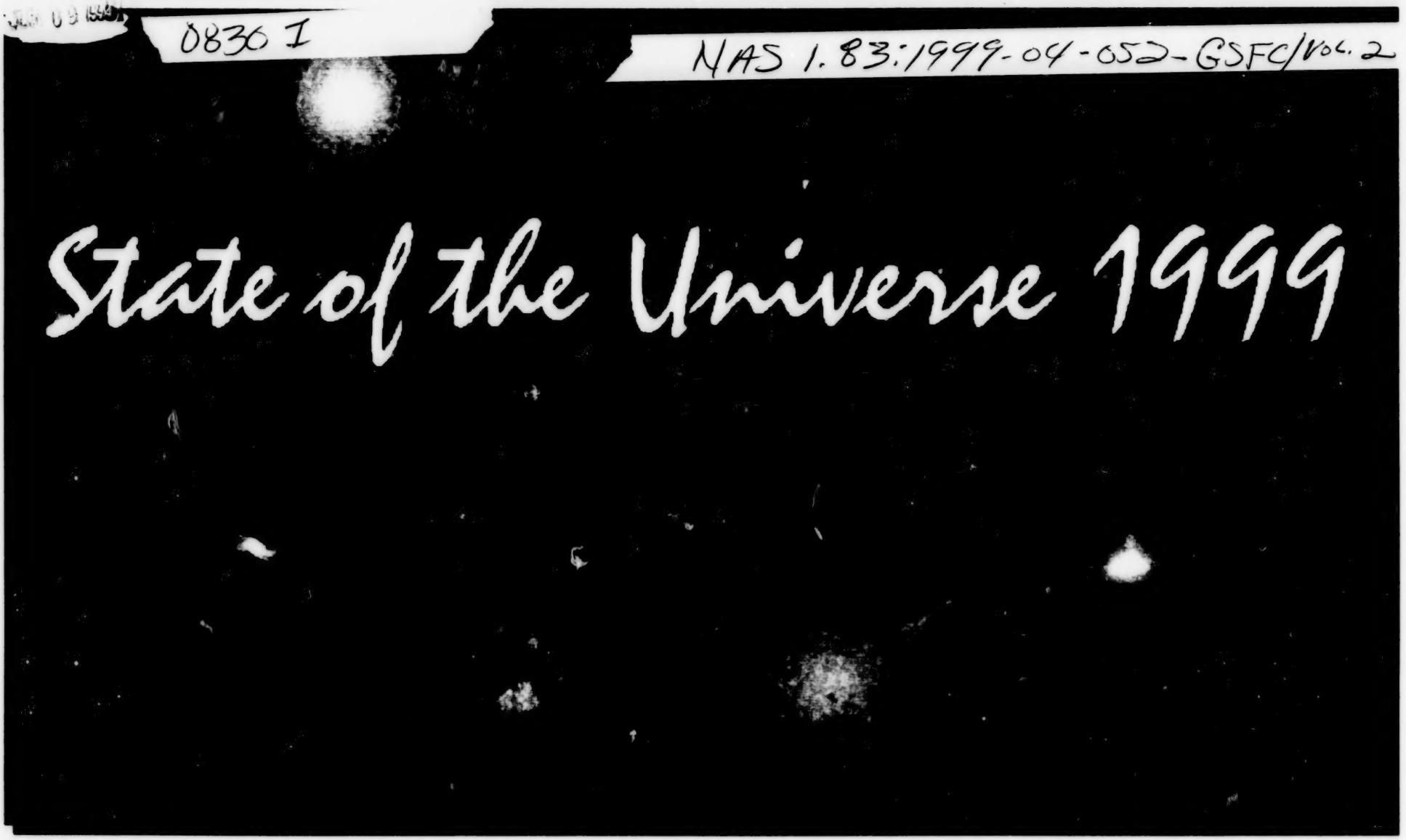
0830 I
NAS 1.83:1999-04-052-GSFC/Vol. 2

State of the Universe 1999



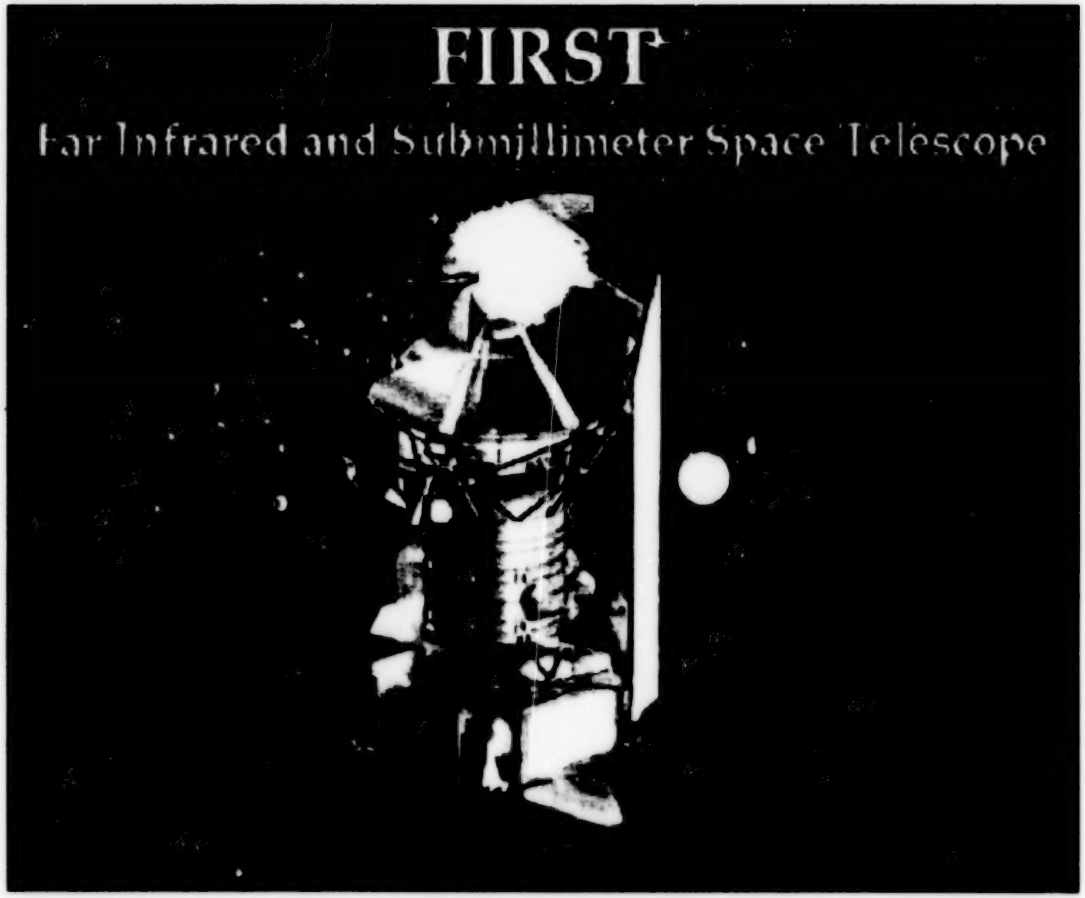
SEU Presentation to the Associate Administrator
Office of Space Science
May 18, 1999
Volume 2

20030162514

AGENDA - Afternoon Session
The Future, Volume 2

Video: "Journey to a Black Hole"	**12:30-12:35**		
Missions:	**12:35-2:05**		
FIRST - Far InfraRed and Submm space Telescope		**G. Parks**	**15 min.**
Planck Surveyor		**G. Parks**	**15 min.**
GLAST - Gamma ray Large Area Space Telescope		**S. Lambros**	**30 min.**
Constellation X-ray Mission		**J. Grady**	**30 min.**
BREAK	**2:05 -2:20**		**15 min.**
Studies:	**2:20-3:10**		
ACCESS - Advanced Cosmic ray Composition Experiment for Space Station		**B. Park**	**15 min.**
LISA - Laser Interferometer Space Antenna		**W. Folkner**	**15 min.**
ARISE - Advanced Radio Interferometry between Space and Earth		**A. Chmielewski**	**10 min.**
OWL - Orbiting Wide-angle Light collectors Mission		**J. Galloway**	**10 min.**
Concluding Remarks	**3:10-3:20**	**A. Bunner**	
Feedback from the AA	**3:20-3:30**	**E. Weiler**	

Far Infrared and Submillimeter Telescope (FIRST)



Gary S. Parks

Jet Propulsion Laboratory

http://astro.estec.esa.nl/SA-general/Projects/First/first.html

FIRST Science Objectives

• Galaxies in the Early Universe

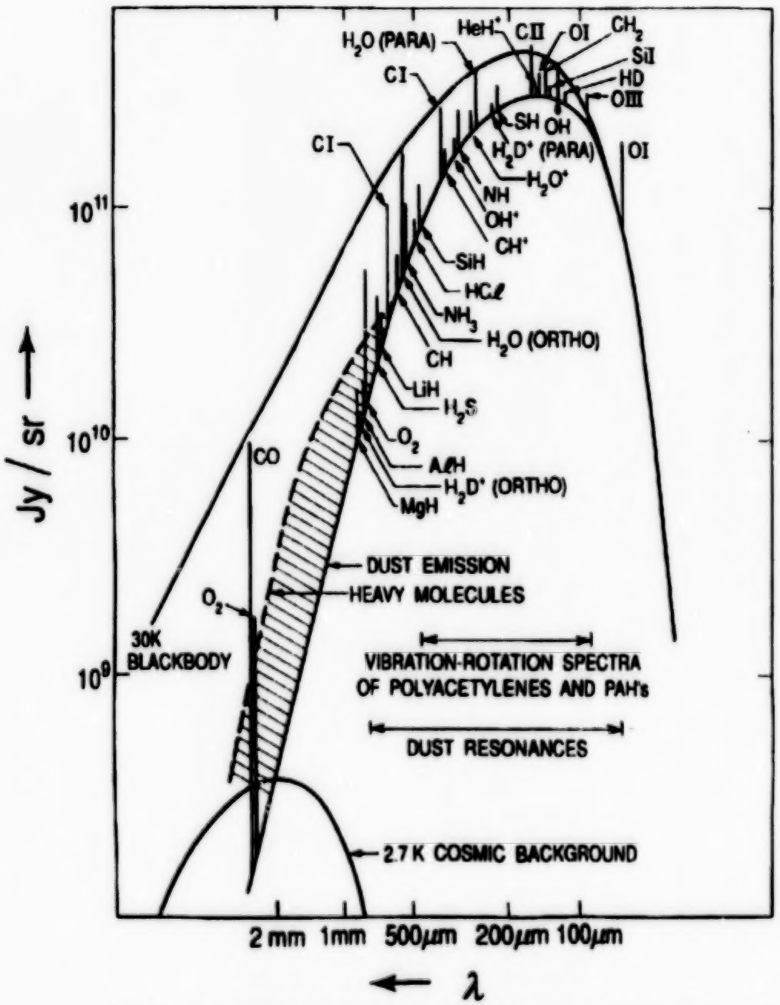
FIRST will observe the earliest dusty galaxies in the Universe. This will allow detailed studies of these galaxies, the star formation history of the Universe, the early evolution of quasars, and the large scale structure of the Universe at high redshift.

• Energetics of Galactic Evolution

FIRST will observe diffuse atomic clouds and quiescent molecular clouds. The brightest molecular, atomic, and ionic lines in the interstellar medium (ISM) are in the far-IR and submm band. These observations will revolutionize our understanding of the structure, energetics, and dynamics of the ISM.

• Stellar Life Cycle

FIRST will study the details of how stars form and the ashes of their death. It will observe the gas and dust injected by dying stars into the interstellar medium, the processing of gas and dust in various phases of interstellar clouds, and the eventual condensation into new stars and planetary systems



The far-IR/submm is the primary band for line and continuum radiation from cool (5-100 K) gas and dust.

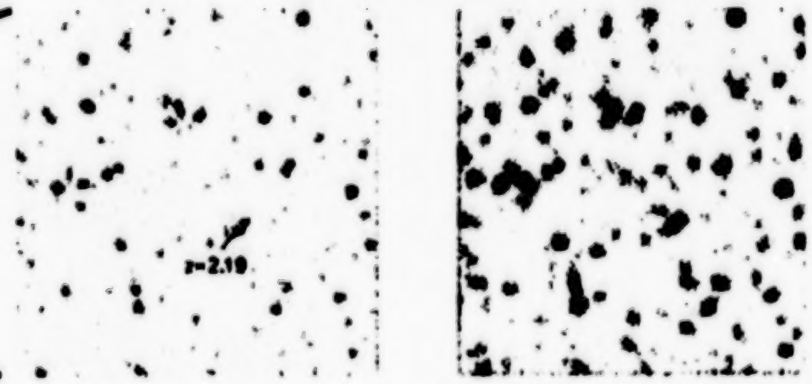
FIRST Capabilities

FIRST will resolve most of the Far-IR background into individual, distant, dusty galaxies near the time of their formation.

ISO survey (175 μm)

Puget et al. 1999

FIRST Simulated Observations



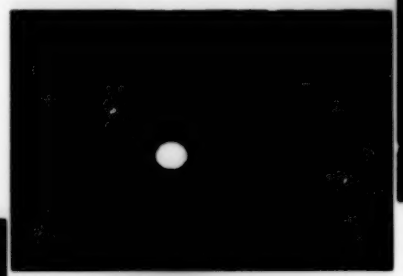
170 μm 250 μm

This simulation shows the substantial increase in angular resolution and sensitivity of the FIRST instruments that will allow detection of distant, primitive galaxies.

The Fifth Great Observatory

FIRST – American Access to a Fifth Great Observatory for the Price of a MIDEX

FIRST
(Far IR & Submm)



SIRTF (IR)

HST (UV/Visible)

AXAF (X Rays)

CGRO (Gamma Rays)

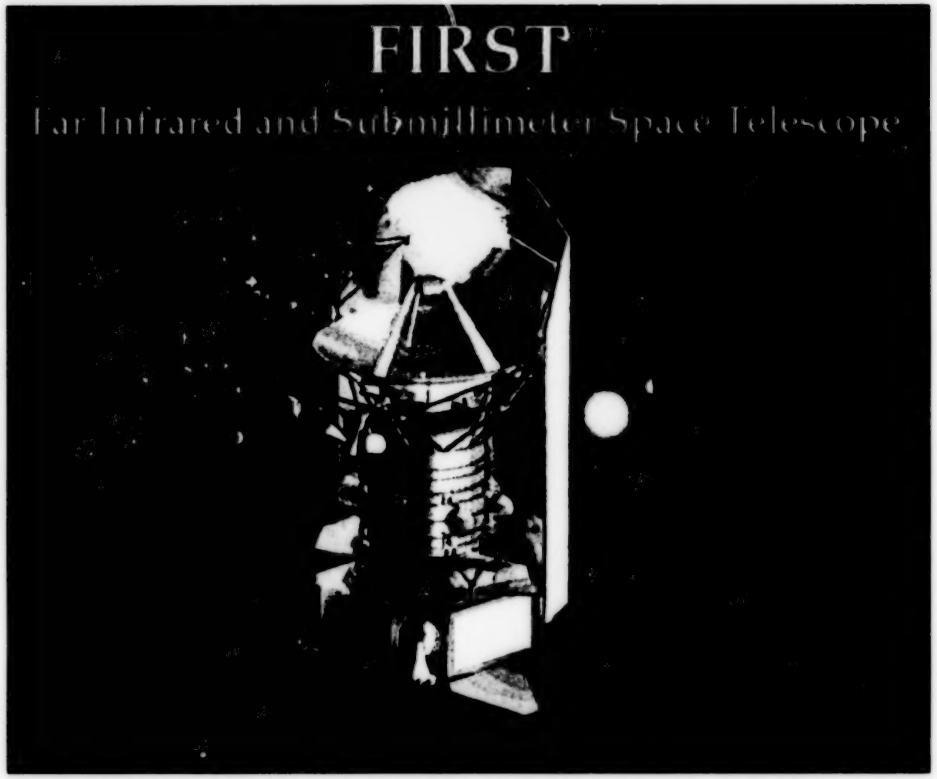
Completing the Spectrum Coverage

NASA Payoff for FIRST Participation

- **NASA payoff is large compared to the fractional budgetary investment**
  - NASA investment is approximately 10% of the mission costs
  - However, the science payoff to the U.S. will likely be equal opportunity for open and key science observation time
  - Specific NASA/ESA negotiation concentrated on adequate U.S. participation on the FIRST Observatory Time Allocation Committee
- **Payoff is large because NASA is contributing key technologies to FIRST, substantially enhancing the mission**
  - Greater spectral coverage
  - Greater observatory sensitivity

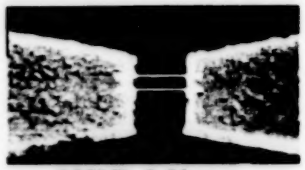
FIRST Mission Concept

- **Observatory-class submillimeter mission**
- **4th ESA cornerstone mission**
- **Three instruments**
  - HIFI (NASA participation)
    - > Spectroscopy
    - > 110um-625um, $R=10^6$
  - SPIRE (NASA participation)
    - > Imaging photometry
    - > 200um-670um, $R=10^{3.5}$
    - > Broadband Spectroscopy
  - PACS (no US participation)
    - > Photometry 80um-210um
    - > Broadband Spectroscopy
- **>3-year mission in L_2 halo orbit**
- **Launch on Ariane 5 in 2007**



U.S. Contribution to FIRST

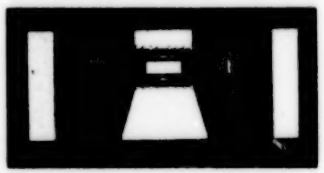
Submillimeter Devices



HEB Mixer

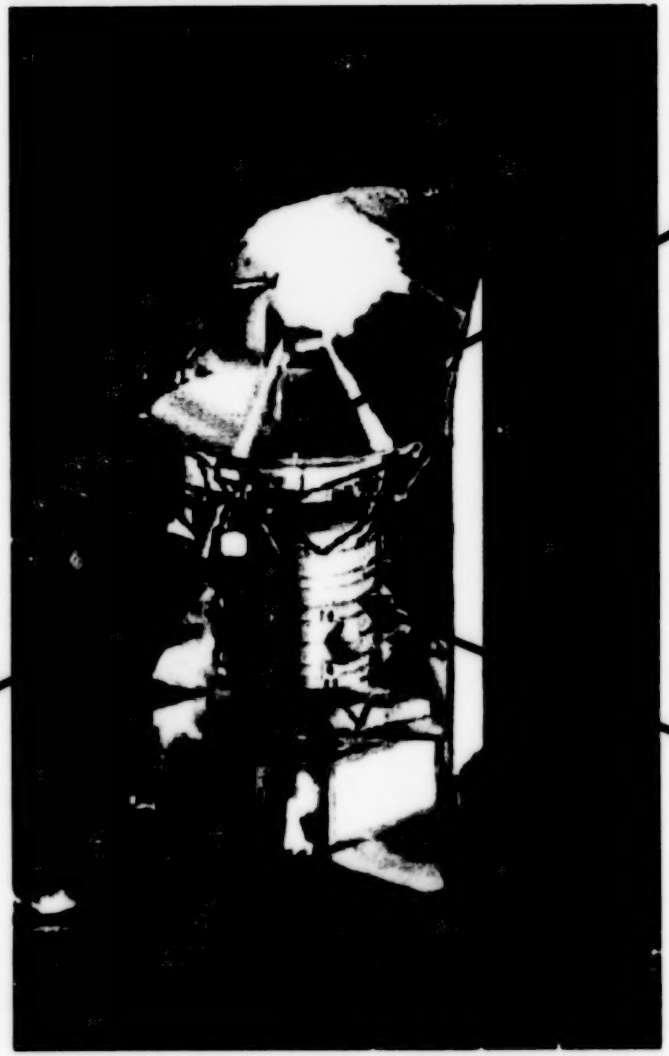
Twin slot SIS Mixer

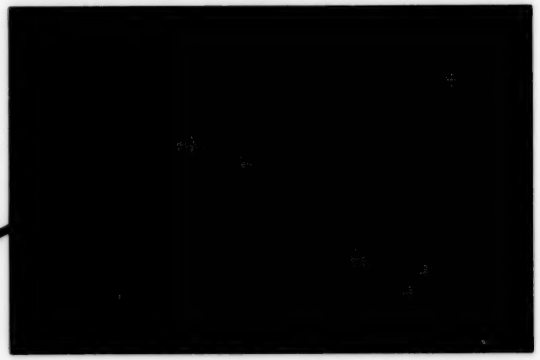
92 GHz MMIC Amplifier



MMIC Multiplier

HIFI





Telescope

Bolometer Array
Spire

FIRST Telescope Development

Roadmap

Technology

Implementation

FY'99 | FY'00 | FY'01 | FY'02

1.5um Segment of 2-meter

2-meter 2um Reflector

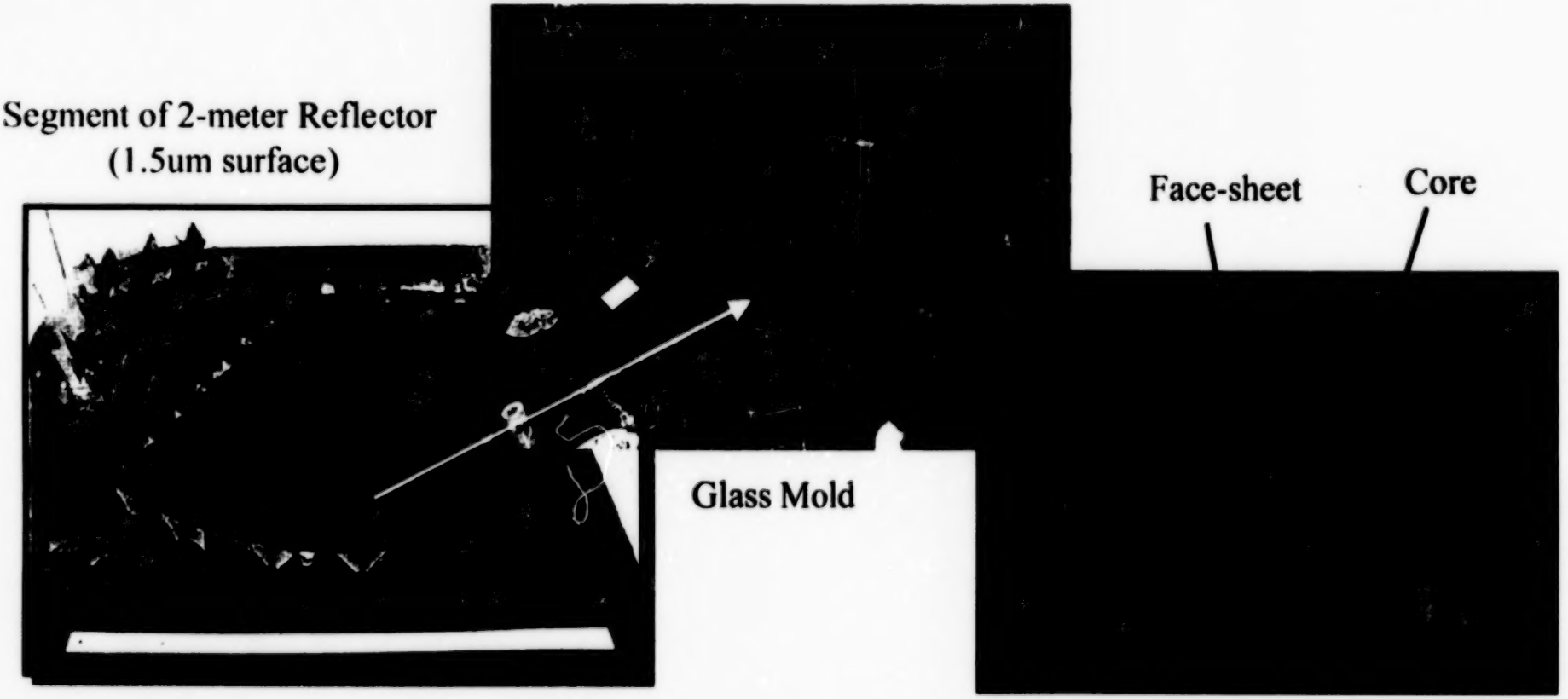
2.5um Segment of 3.5-meter

PDR

CDR

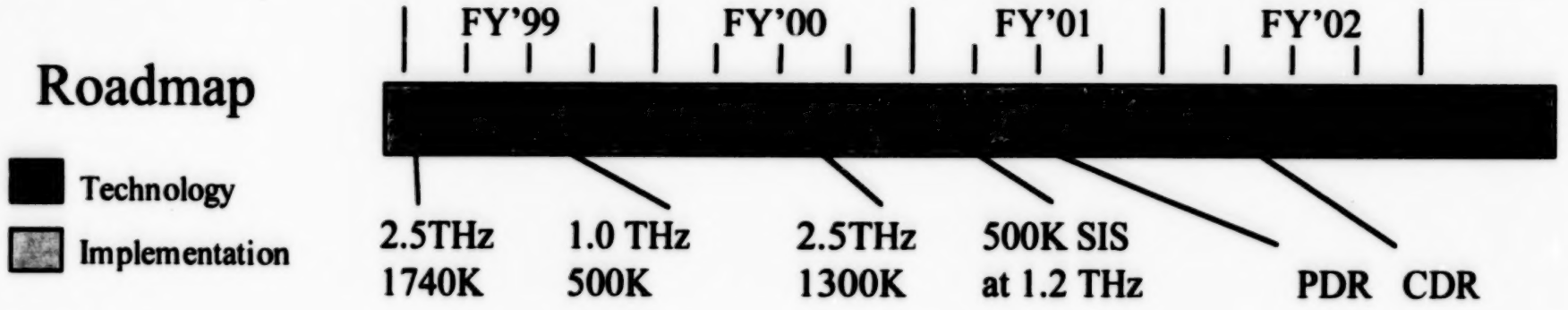
QM Delivery

Segment of 2-meter Reflector
(1.5um surface)

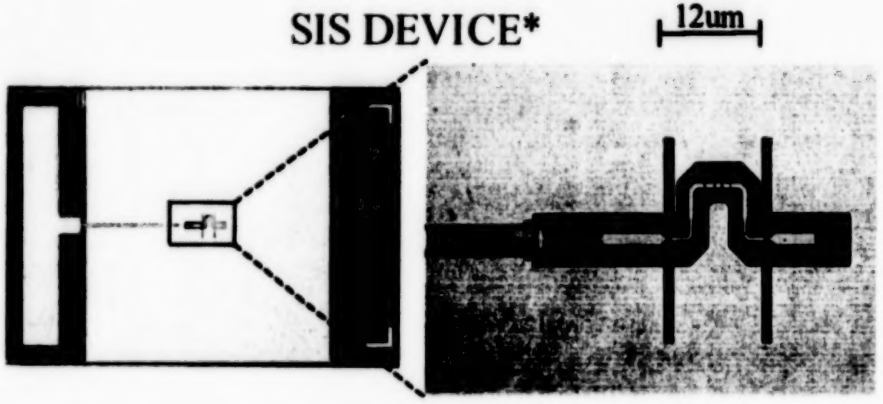


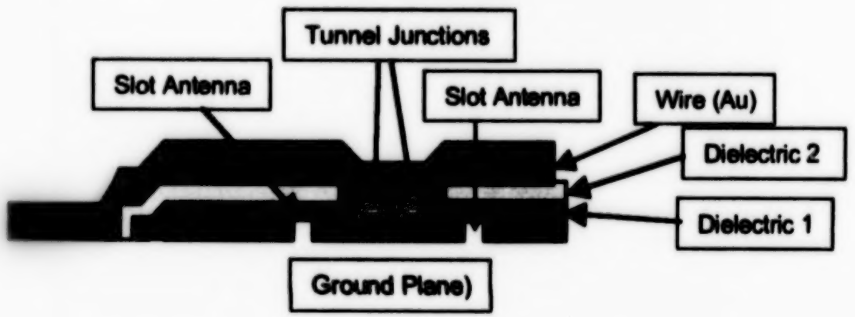
FIRST HIFI Mixer Development

Roadmap

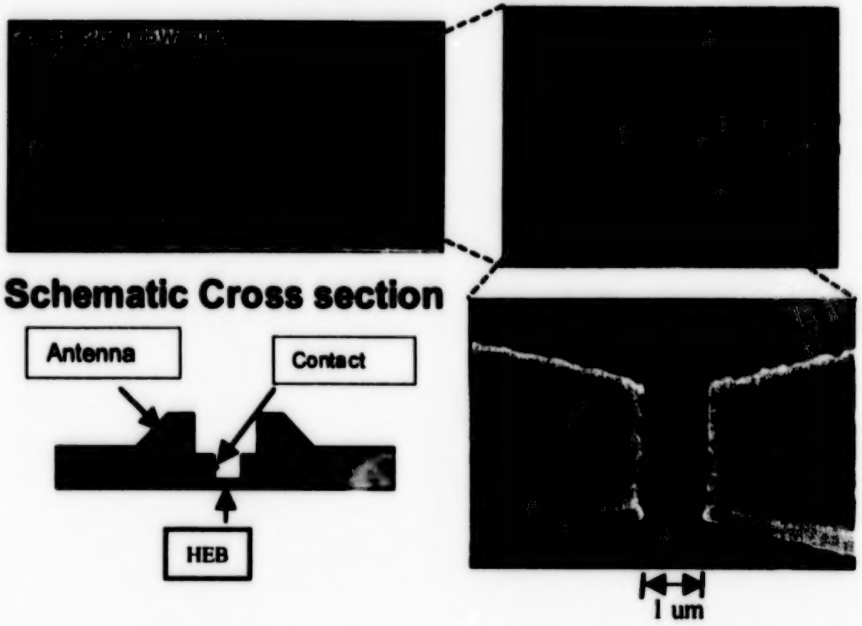


SIS DEVICE*





HEB DEVICE**

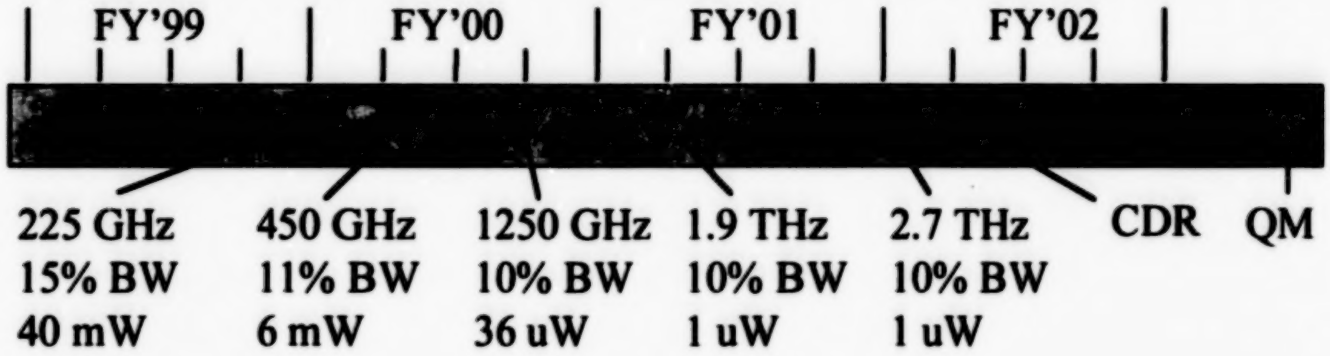


* Superconducting Insulator Superconductor (SIS) mixer

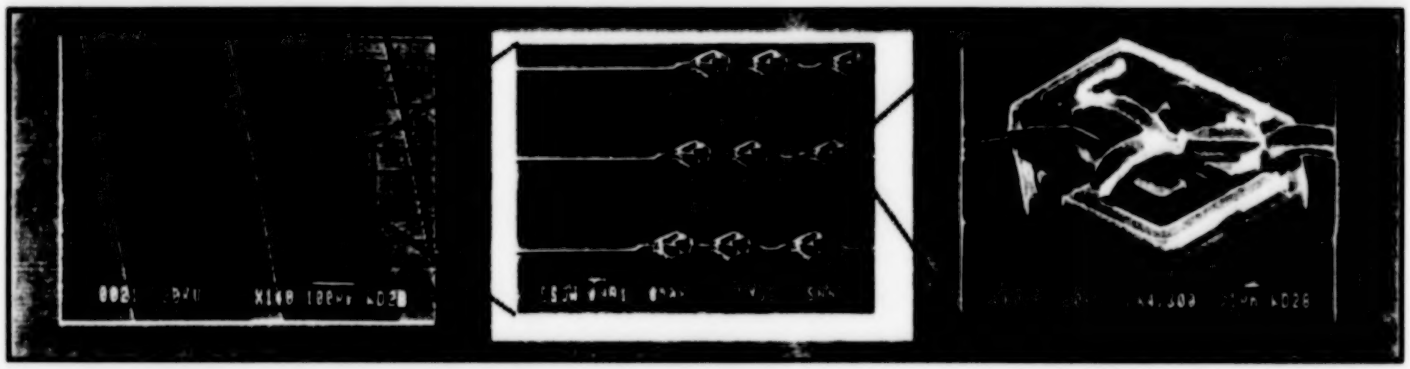
** Hot Electron Bolometer (HEB) mixer

FIRST HIFI Local Oscillator Development

Roadmap



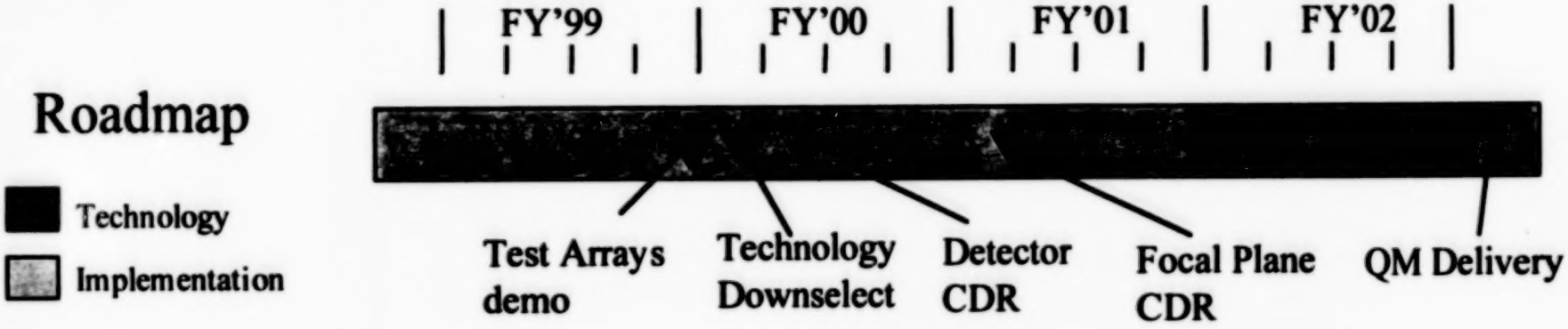
Diode Device Technology



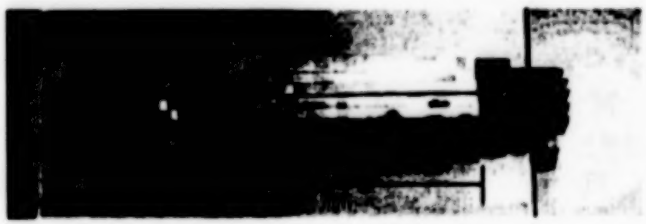
Frequency Multiplier Technology

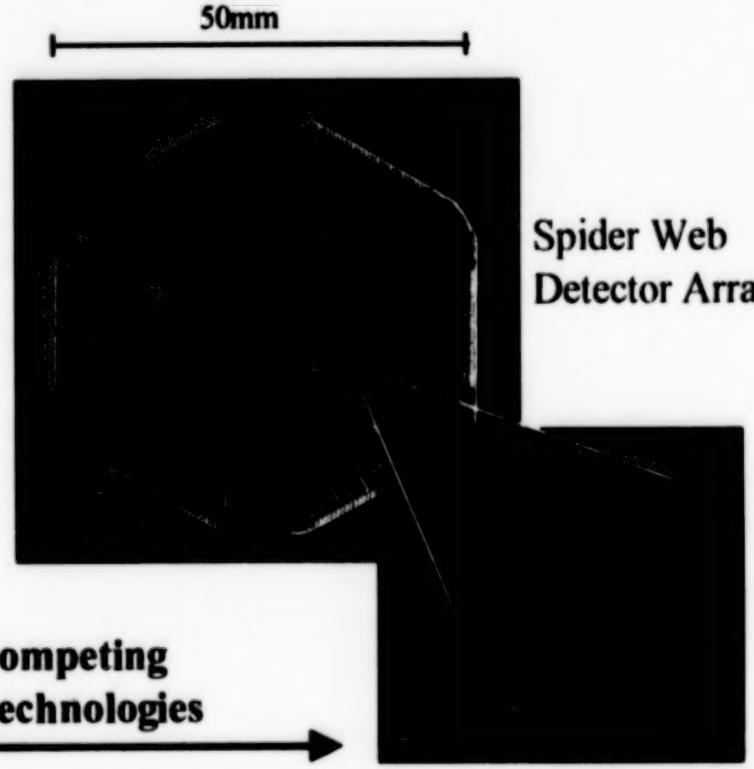
FIRST Spire Detector Development

Roadmap



Silicon Pop Up Device (SPUD)





Competing Technologies

First Budget Requirements

FIRST DEVELOPMENT BUDGET (REAL YEAR $M)*

Fiscal Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Total
Phase A											
Phase B											
Phase C/D											
Eng. Studies	1.05	1.87	0.32	0.34	0.35	0.36	0.38	0.39	0.41	0.20	5.47
Telescope	[illegible]										
Mission Scientists		0.21	0.22	0.22	0.23	0.24	0.25	0.25	0.26		1.88
HFI	[illegible]										
Spire	1.00	2.08	2.64	4.16	3.71	3.57	1.50	0.25	0.26		19.17
Inst. Team & Ctr.	[illegible]										
Total	5.00	10.65	12.61	19.40	19.40	19.40	10.04	4.05	4.21	0.20	104.76
POP Guidelines	5.00	6.70	12.61	19.40	19.40	19.40	16.54				
Delta	0	-3.95	0	0	0	0	0				

Note: FY98 guidelines were met by deferring $950K of spending to FY99 and borrowing $3M from NGST. These funds have been added to FY99 guidelines to meet project requirements.

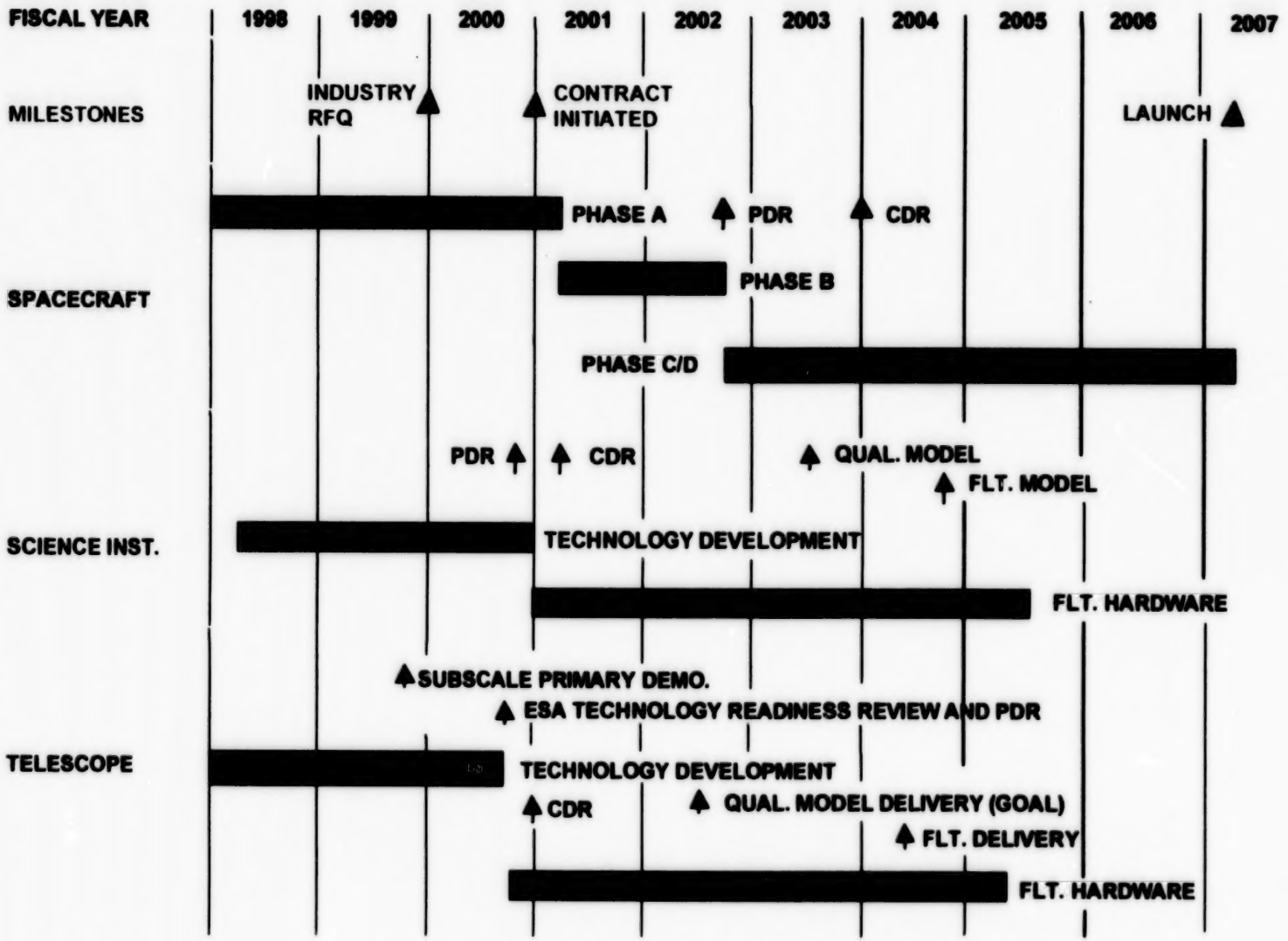
Budgets are approximately 15% lower than estimates. These guidelines were met by eliminating the deep space X-band transponder, reducing and delaying the science center algorithm development by one year, cost-capping the development budgets for the telescope, HFI and Spire instruments, and eliminating integration support in FY06 when the spacecraft will be at the launch site.

FIRST SCIENCE BUDGET (REAL YEAR $M)

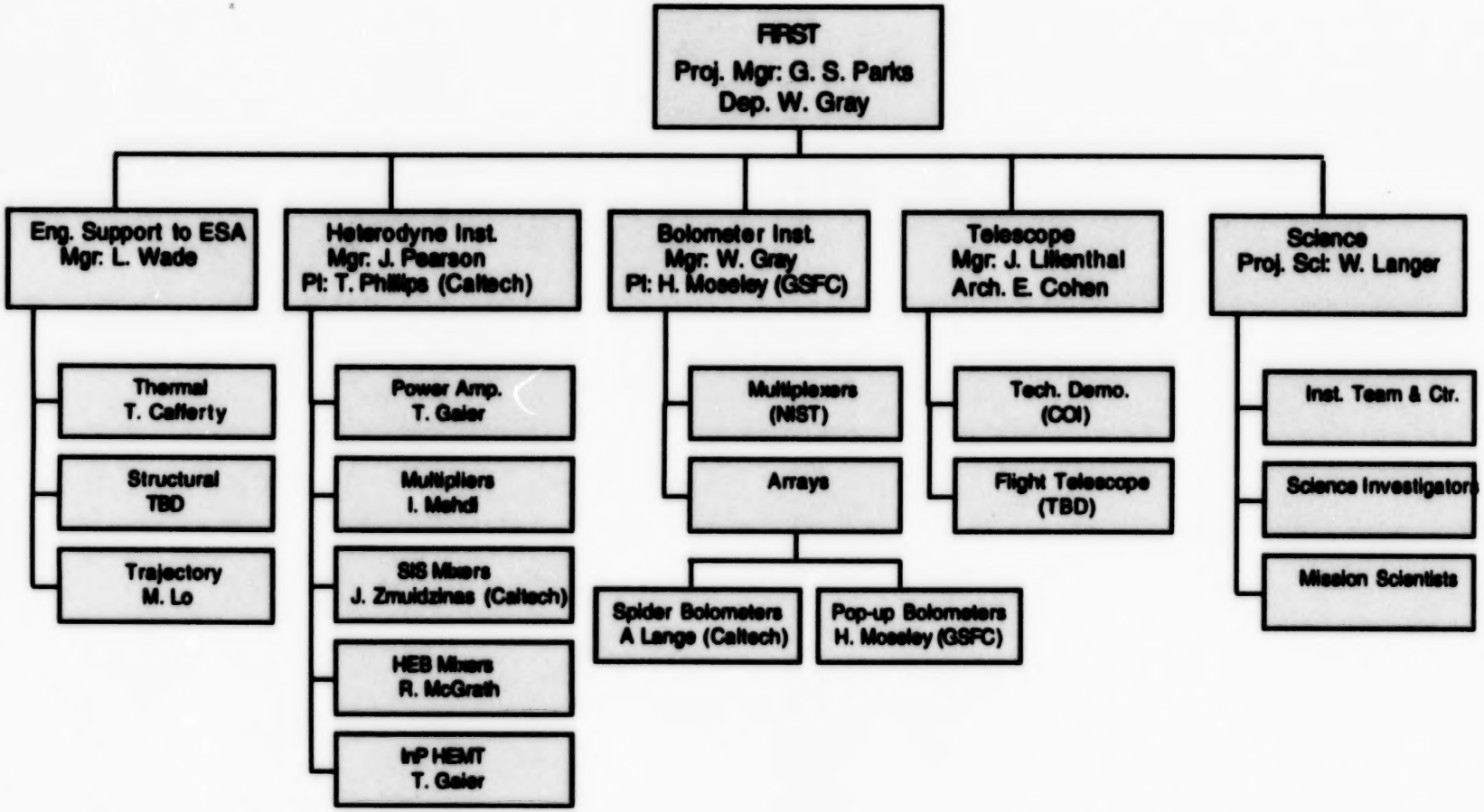
Fiscal Year	2007	2008	2009	2010	2011	2012	2013	2014	Total
Phase E									
Inst. Team & Ctr.	2.8288	2.93	3.04	3.17	3.30	3.42	3.58	0.00	22.25
SS. [illegible]									
Mission Scientists	0.2608	0.29	0.30	0.31	0.33	0.34	0.18	0	2.04
DSN [illegible]									
Total	6.48	6.48	6.79	9.14	9.52	8.94	9.58	1.85	62.77

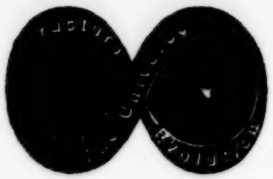
*Assumes Generic Code SM program provides $1M in 1999 and $0.5M in 2000 for heterodyne technology and $0.3M in 1999 and 2000 for bolometer technology

FIRST Top Level Schedule



FIRST Organization Chart



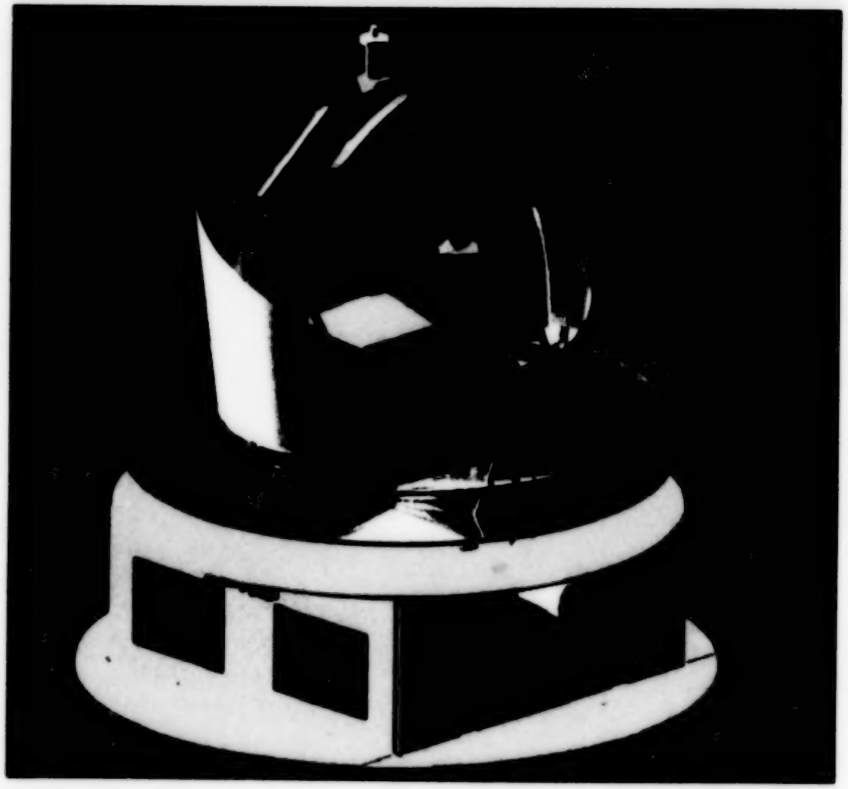


Outlook for FIRST

- **One year from now**
  - Technology demonstrated for Telescope, Spire detectors, and HIFI frequencies < 1THz
  - Downselect completed for SPIRE detectors
  - HIFI mixer technology downselect completed and acceptable performance demonstrated to 2.7 THz

- **Five Years from now**
  - All qualification model hardware delivered to ESA
  - Qualification model hardware fully integrated and tested at the system level
  - Flight model hardware delivered and ready to begin system level tests

Planck



Gary S. Parks

Jet Propulsion Laboratory

http://astro.estec.esa.nl/SA-general/Projects/Planck/

Planck Science

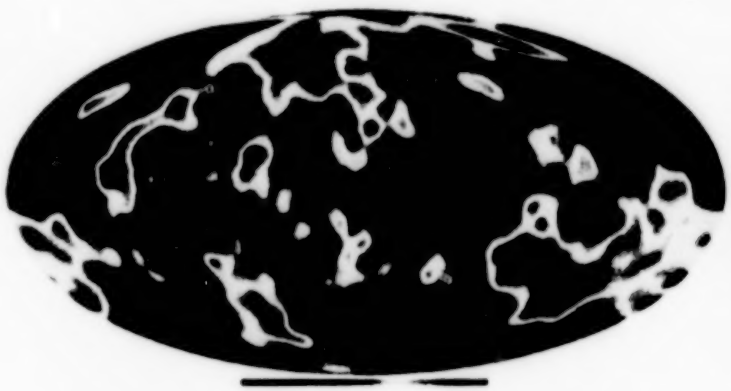
- **Planck's measurement of the small-scale anisotropy of the Cosmic Microwave Background (CMB) will revolutionize cosmology.**
- **Planck will answer fundamental questions, such as:**

How old is the Universe ?
How fast is it expanding ?
Will it expand forever ?

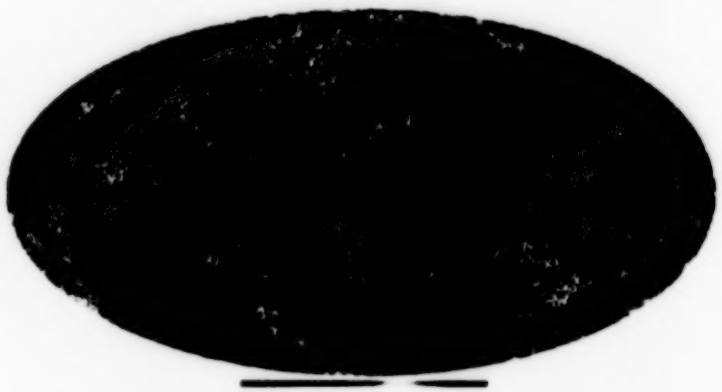
How much dark matter is there ?
When did the first stars form ?
Is there a cosmological constant ?

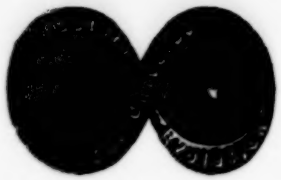
- **Planck will measure CMB anisotropy to unprecedented accuracy and resolution.**

COBE Resolution



Planck Resolution



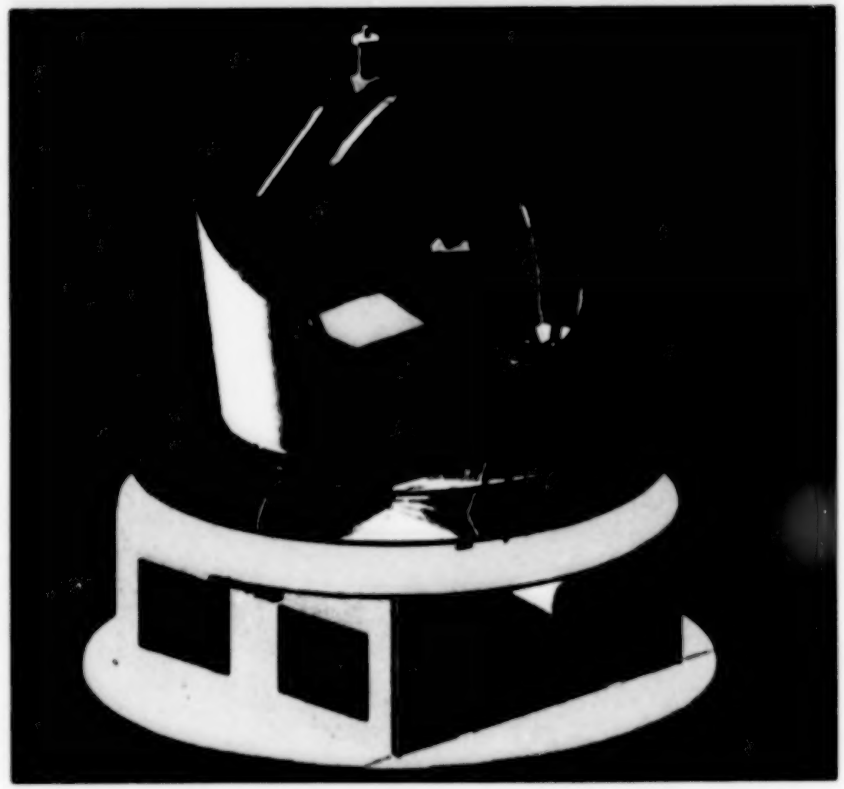


Planck Mission Capabilities

- **Planck is the third generation space CMB mission, following COBE and MAP. It will:**
  - Measure CMB anisotropies on all angular scales > 5', with an accuracy set by astrophysical limits.
  - Have unprecedented combination of sky coverage, angular resolution, sensitivity, and broad frequency coverage.
  - Have more than 6 times better sensitivity after foreground removal and 2.5 times better angular resolution than MAP.
  - Produce all-sky surveys of all major astrophysical sources of microwave emission with 100 times better angular resolution than existing surveys.
  - Detect all clusters of galaxies that can be observed by Chandra, XMM, and future X-ray observatories, including the first clusters formed in the Universe.
  - Measure the brightest radio, submillimeter, and far-infrared extragalactic sources over the whole sky allowing further study with future instruments.

Planck Mission Concept

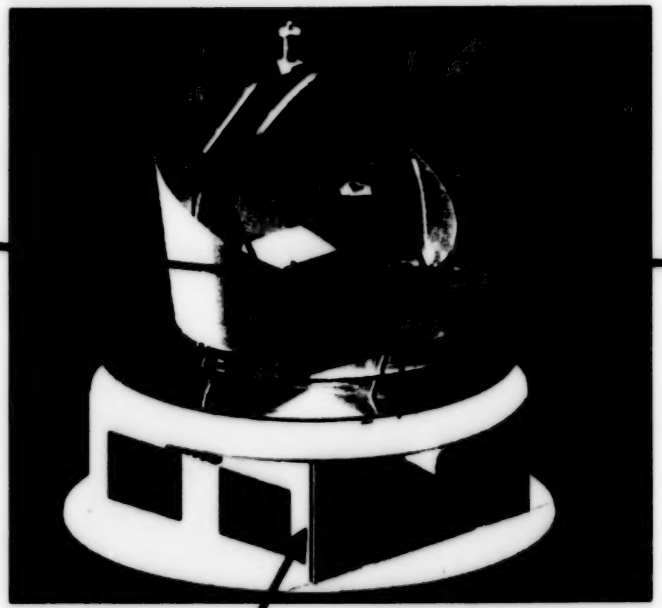
- 3rd Mid-Sized mission in ESA's Horizon 2000 program
- Two actively cooled instruments
  - LFI (NASA Participation)
  - HFI (NASA Participation)
- Telescope passively cooled to <60K
- 2 year mission in L_2 halo orbit
- 1 rpm spin rate
- Complete sky map in 6 months
- Launch with FIRST on Ariane 5 in 2007



US Contributions to Planck

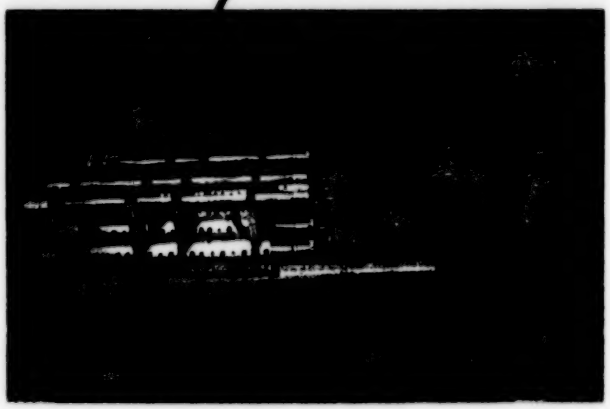
LFI

Cryogenic low-noise amplifier technology



HFI

Spider Web Bolometers

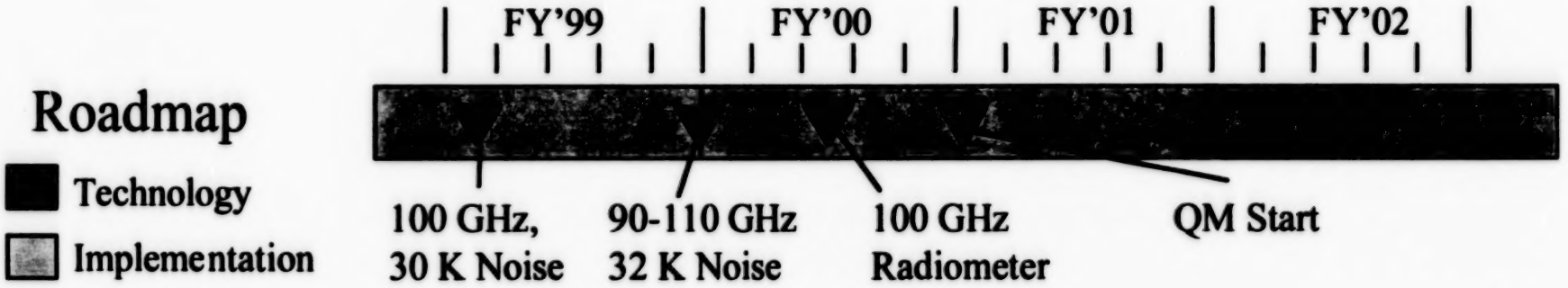


20K Sorption Cooler

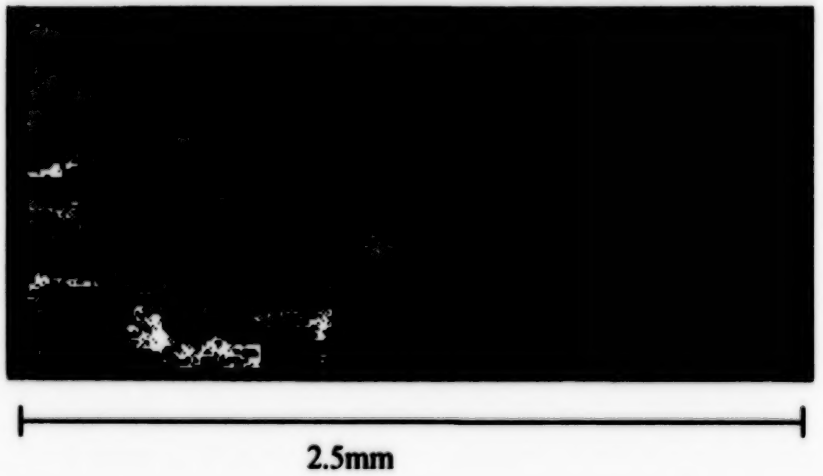
LFI and HFI

Planck Low Noise Amplifier Development

Roadmap

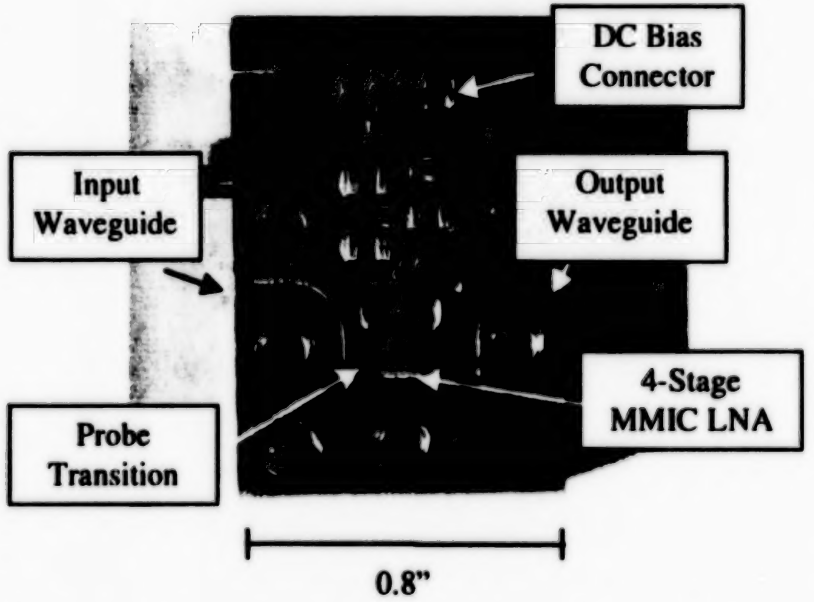


3-Stage MMIC* Low Noise Amplifier

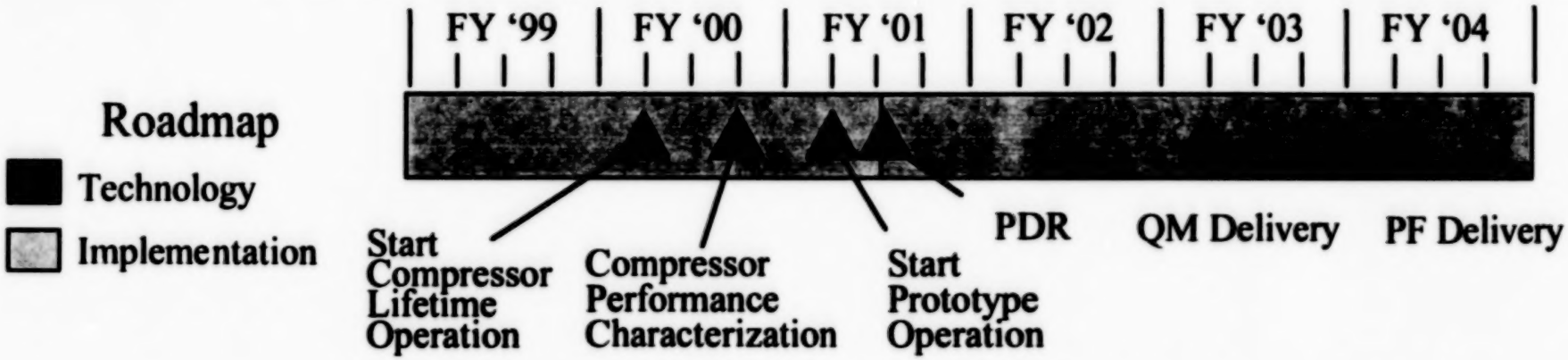


*Microwave Monolithic Integrated Circuit (MMIC)

Amplifier Assembly

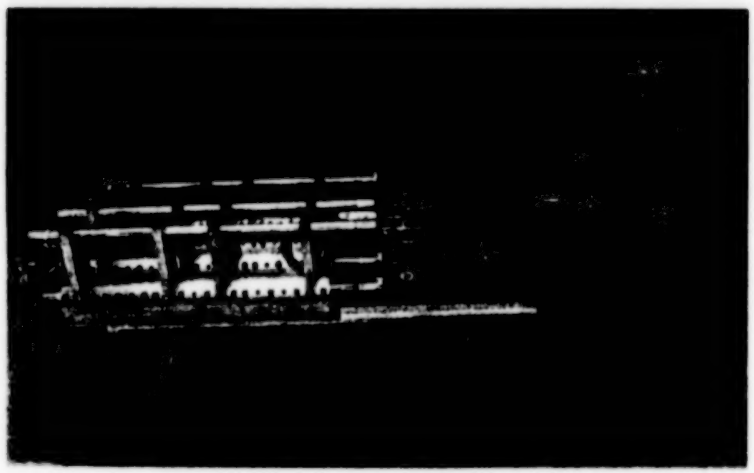


Planck Sorption Cryocooler Development

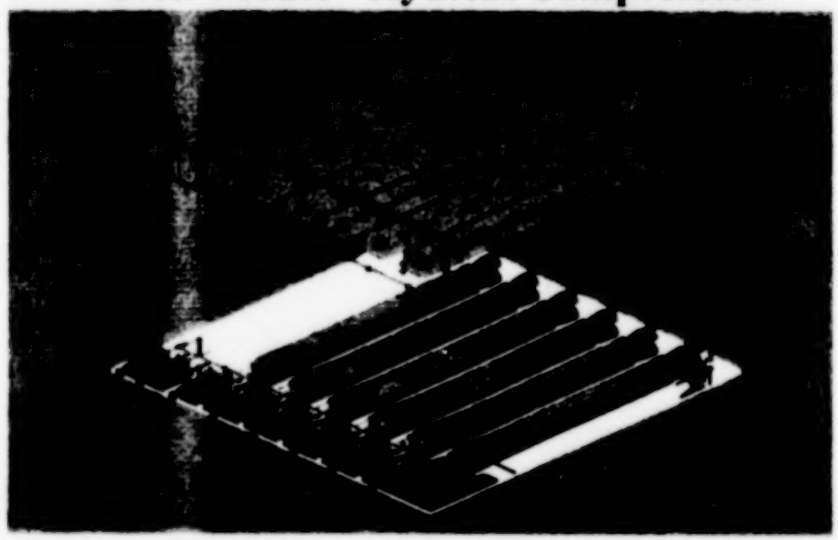


State of the art = 1000 hours lifetime
Requirement = 25000 hours lifetime

Breadboard Cooler Assembly

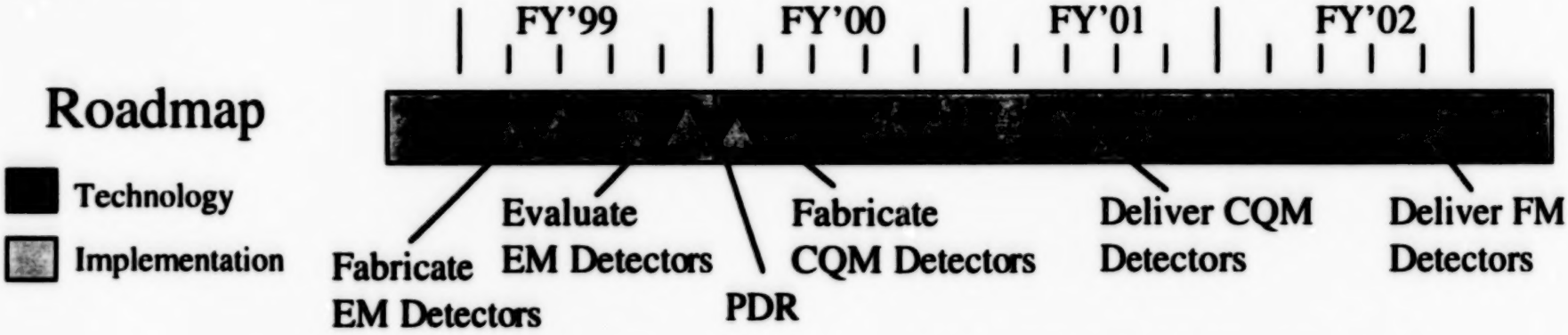


CAD Model - Hydride Compressors

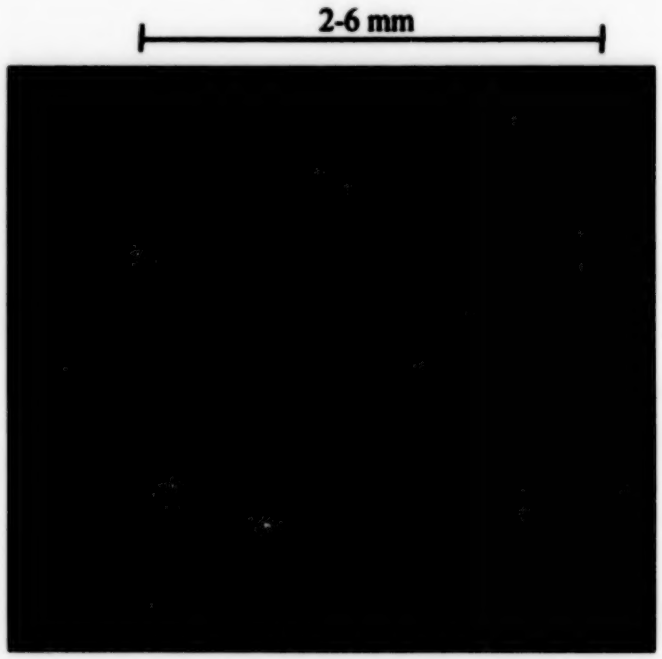


Planck HFI Bolometer Development

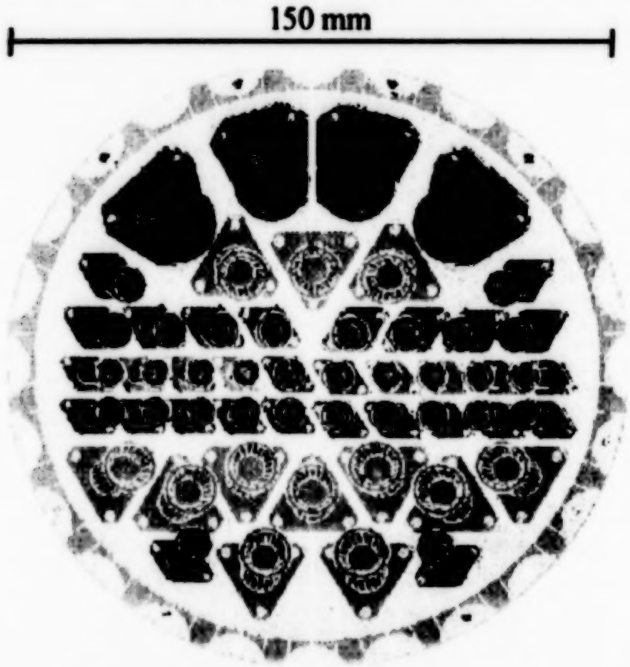
Roadmap



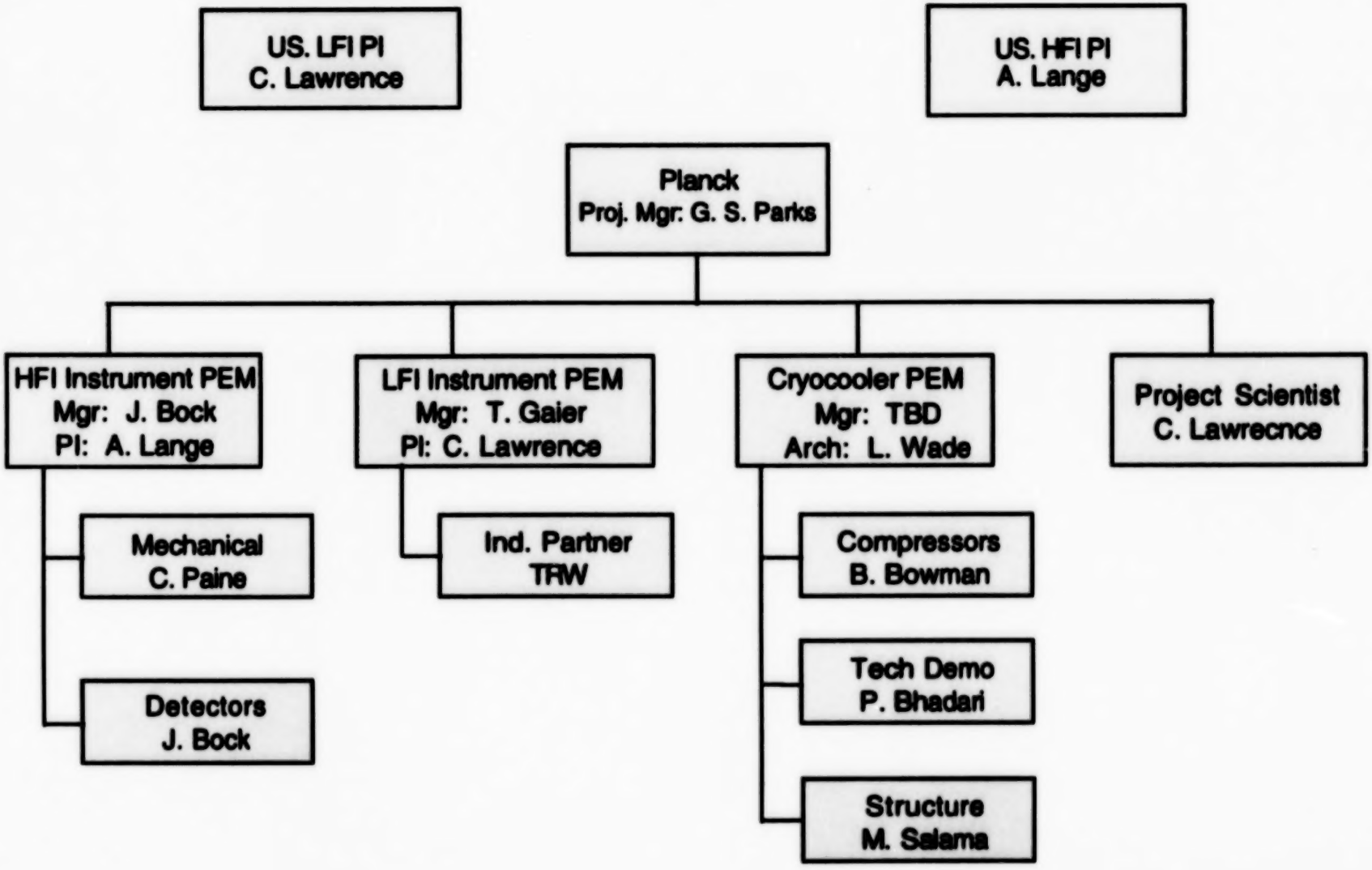
Spider Web Detector



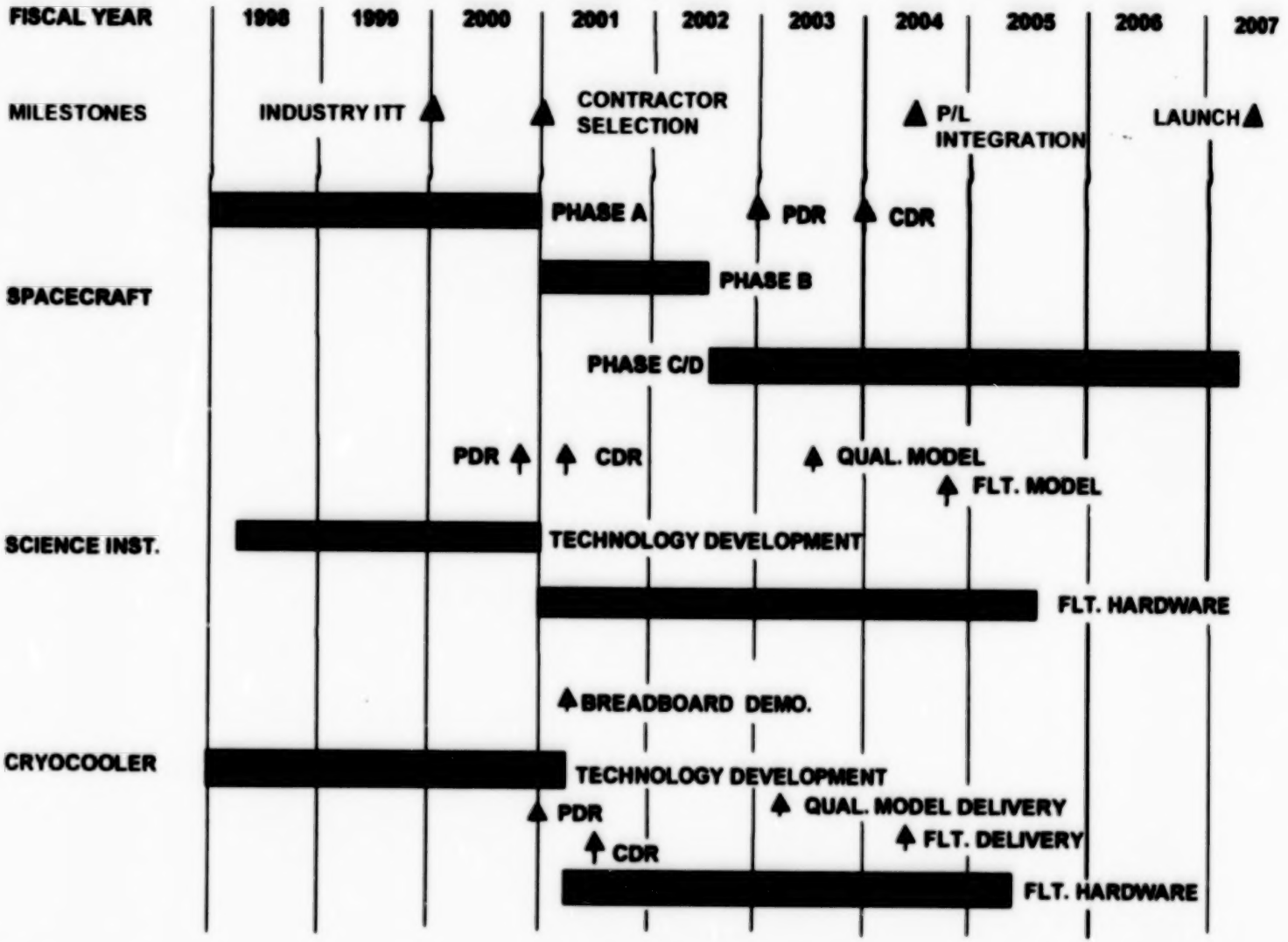
Bolometer Array (each color shows a specific frequency band)



Planck Organization Chart



Planck Top Level Schedule



Planck Budget Requirements

PLANCK DEVELOPMENT BUDGET (REAL YEAR $M)

Fiscal Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Total
Phase A												
Phase B												
Phase C/D												
Cryocooler tot	0.09	0.45	1.50	2.37	2.36	2.77	2.67	1.94	0.48	0.33	0.45	15.32
HFI Tot	[illegible]											
LFI tot	0.24	0.83	0.71	0.85	0.50	0.47	0.46	0.48	0.21	0.22	0.18	4.91
Total	[illegible]											
HQ Guidelnes	0.7	1.30	3.70	4.60	4.15	4.20	3.90	3.1				24.95
Delta	[illegible]											

Notes:Assumes additional technolbgy program funding of 1) 600k/yr for cryocooler through FY02 2) 300K/yr for HFI thorugh FY02, and 3) 200K/yr for LFI through FY00 and 410K in FY01

PLANCK SCIENCE BUDGET (REAL YEAR $M)*

Fiscal Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total
Phase C/D											
Phase E											
Data Analysis Preparation	[illegible]										
Sci. Investigators					1.20	3.89	4.02	4.16	4.29		17.56
Total	[illegible]										

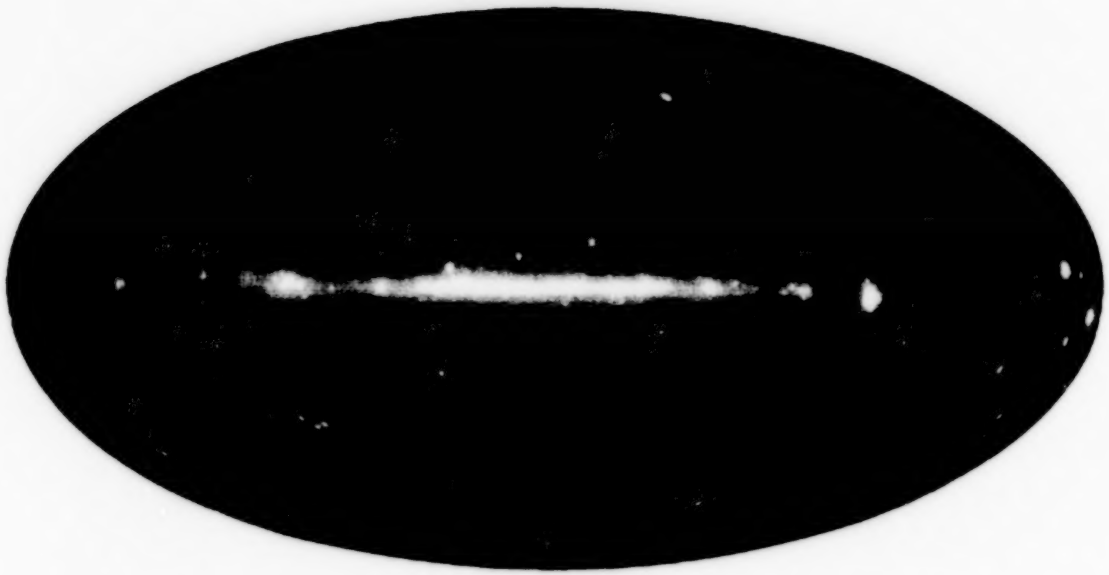
* Proposal only. Not currently in the approved plan

Outlook for Planck

- **One year from now**
  - Technology demonstrated for LFI low noise amplifiers and HFI bolometers
  - Cryocooler compressor performance demonstrated, and life tests begun
  - Cryrocooler / Spacecraft integration design completed

- **Five years from now**
  - All qualification model hardware delivered to ESA
  - Qualification model hardware fully integrated and tested at the system level
  - Flight model hardware delivered and ready to begin system level tests

Gamma-Ray Large Area Space Telescope (GLAST)



Scott Lambros
Goddard Space Flight Center
http://glast.gsfc.nasa.gov/

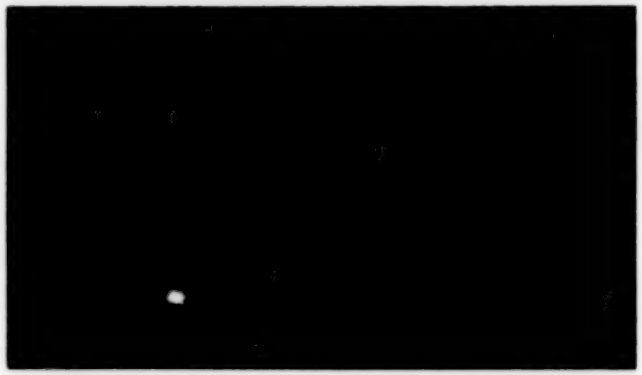
GLAST

Exploring sites of Particle Acceleration in the Universe.

GLAST measures the direction, energy, and arrival time of celestial gamma-rays in the 20 MeV to 300 GeV energy region.

GLAST Science Objectives

HST Image of M87 (1994)

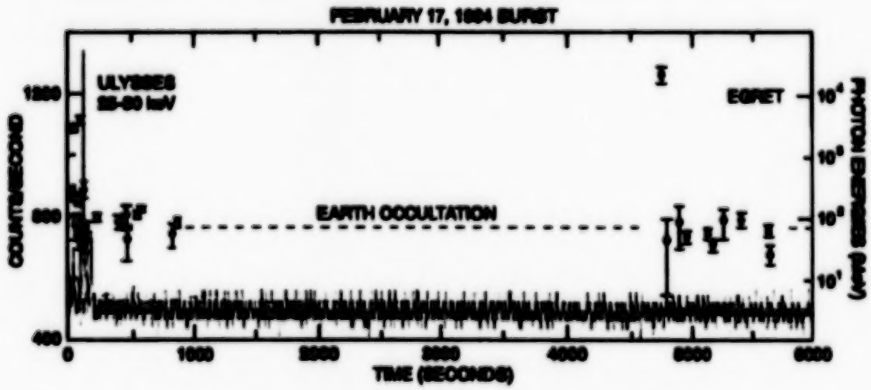


Cosmic Diffuse Background - Isotropic or integrated flux from many as yet unresolved sources?

Active Galactic Nuclei: GLAST will detect 1000's (EGRET detected ~60). The center, believed to be a super massive black hole (1 - 10 billion solar masses), shines brightly in the GLAST energy region.

Cosmology: Extragalactic background light - secrets of galactic (stellar) evolution.

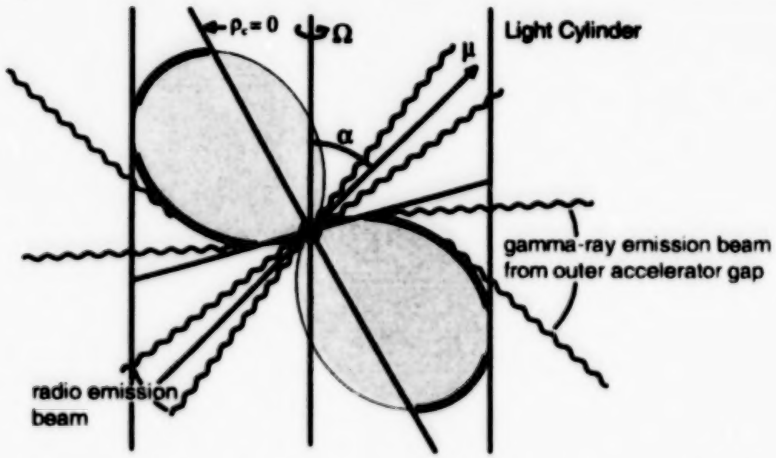
Gamma-ray bursts: What causes these powerful explosions? GLAST will make definitive measurements of high energy behavior.



GLAST Science Objectives

(continued)

Pulsars: Investigate acceleration mechanism, evolution.

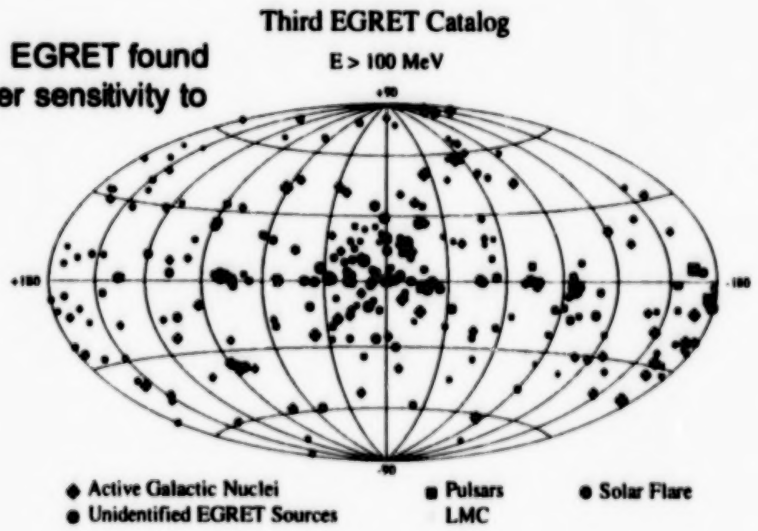


The outer-gap model for pulsar emission

Dark Matter: test the Theory;
WIMP Annihilations?

Solar Physics - high-energy gamma-rays from solar flares.

Unidentified Sources: EGRET found 170; GLAST has higher sensitivity to resolve these.



What can be discovered!!

GLAST Capabilities

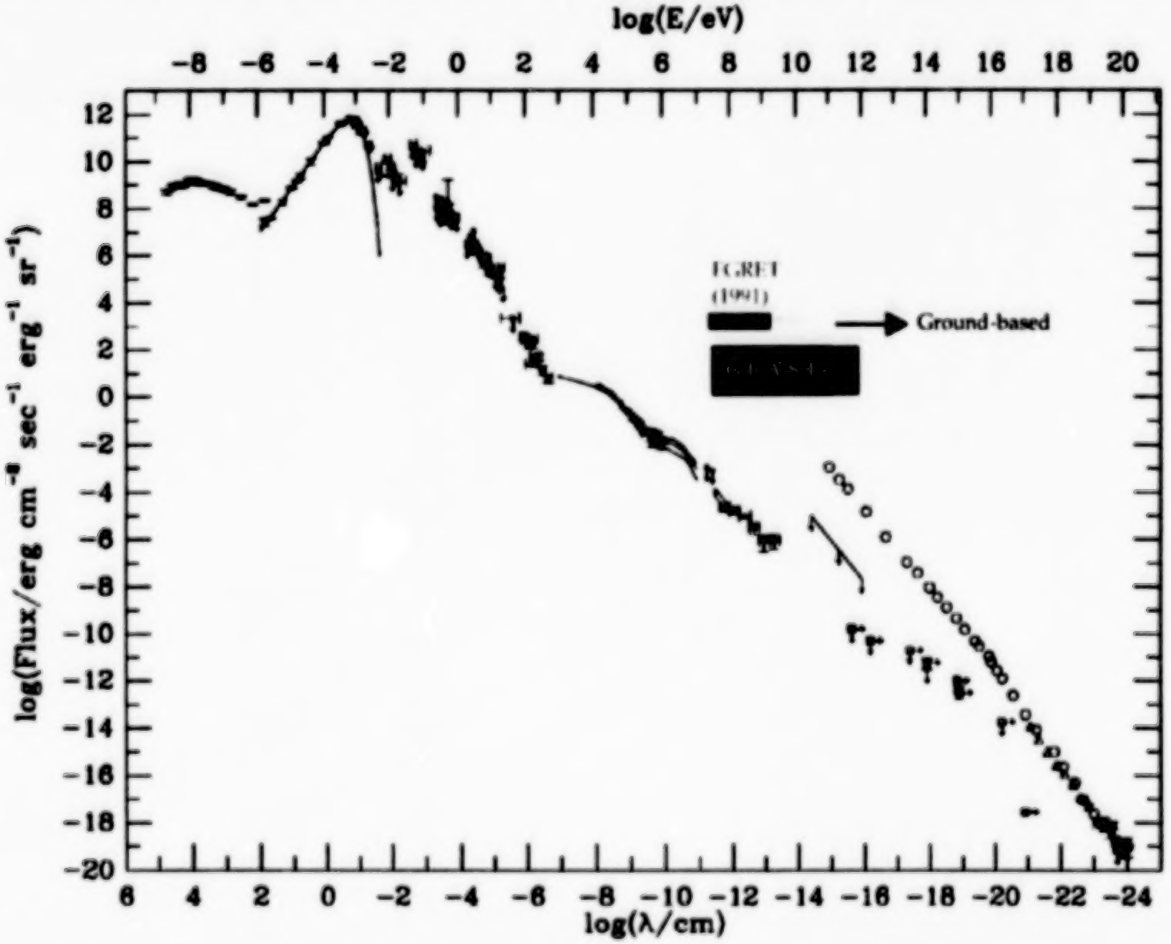
Parameter	CGRO/EGRET	GLAST	Comment
Energy Range	20 MeV to 30 GeV	20 MeV to 300 GeV	GLAST is broadband ~ 4 decades in energy, including unexplored region >10 GeV
Energy Resolution	10%	10%	
Effective Area	1500 cm^2	8000 cm^2	Large area: factor >5 better than EGRET
Field of View	0.5 steradians	2 steradians	Huge FOV: >16% of sky
Angular Resolution	5.8° at 100 MeV	3.5 ° at 100 MeV 0.2° at 10 GeV	Unprecedented PSF for gamma-rays: factor >3 (average) better than EGRET
Sensitivity (>100 MeV)	~1 x 10^{-7} cm^{-2} s^{-1}	~4 x 10^{-9} cm^{-2} s^{-1}	Factor > 25 improvement in sensitivity
Source Location	5 to 30 arcmin	1 to 5 arcmin	
Lifetime	2 year design life. 1991 to present	5 year design life.	5 year design life. No expendables . 10 year goal.

GLAST Capabilities

(continued)

Why this energy range? (20 MeV - > 300 GeV)

GLAST will observe in one of the last poorly measured energy regions.

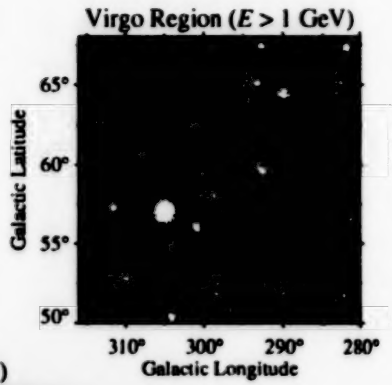


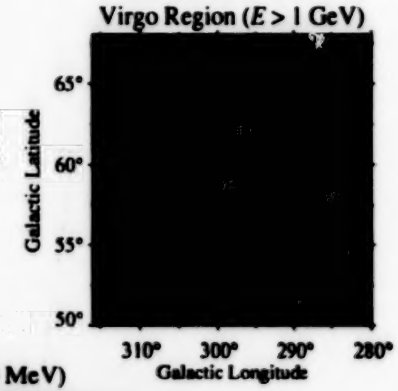
The Flux of Diffuse Extra-Galactic Photons c. 1990, Ressell and Turner

GLAST Capabilities

(continued)

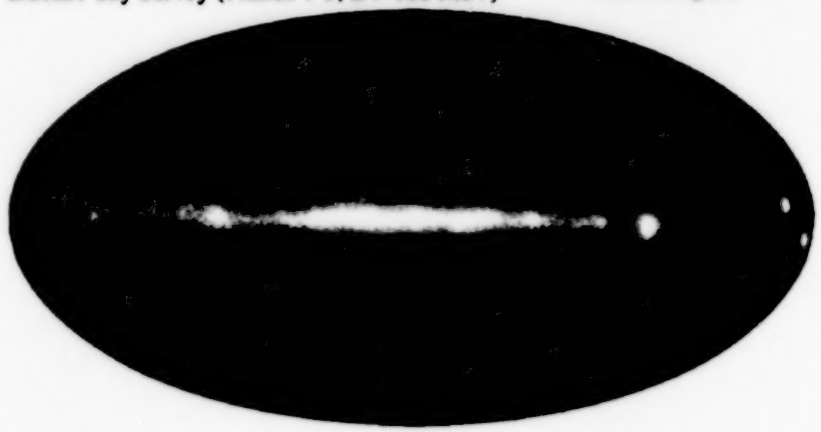
GLAST vs CGRO/EGRET All-Sky Surveys





GLAST Sky Survey (1-year, $E > 100$ MeV)

EGRET Sky Survey (Phases 1-5, $E > 100$ MeV)



GLAST Simulation

EGRET Data

Mission Concept

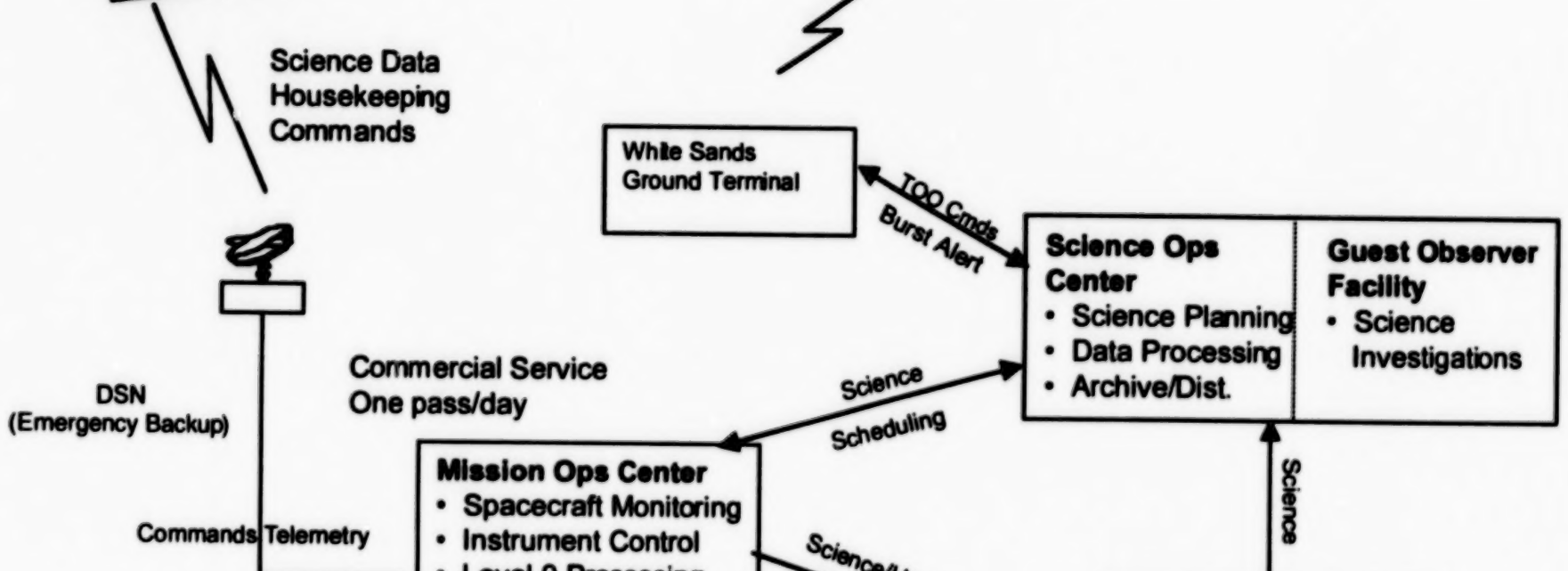
Fiber GLAST
Delta II

- Single, Facility-class instrument, possible secondary instrument.
- Baseline launch vehicle is a Delta 7920 with a 10 foot fairing.
- Orbit: 28.5° inclination, or lower; 550 km. altitude, circular.
- Average data rate = 300 kbps.
- 5 year lifetime; 10 year goal.

- First year of observing is a full sky survey (constant slewing).
  - Interrupted by pointing to targets of opportunity, such as novae and supernovae.
- GRB alert to ground, other instruments.
- After first year: survey and pointed observations driven by guest observer investigations.
- After calibration/verification period, all data is publicly available.

Silicon GLAST
Delta II

Mission Concept - Data Flow

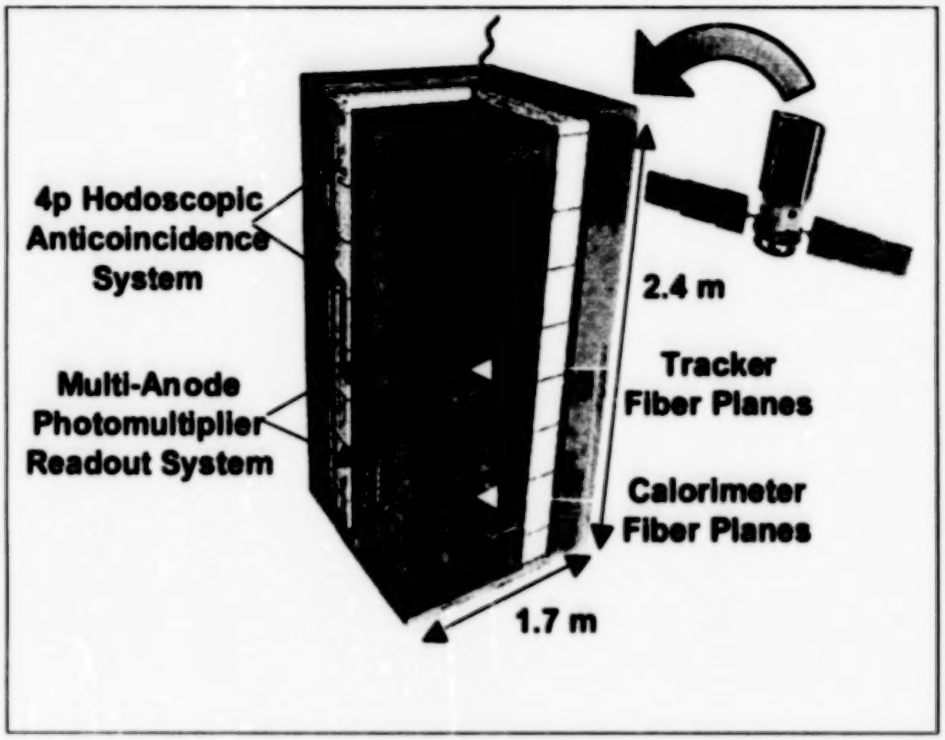


Rev 04/15/99

Acquisition Strategy

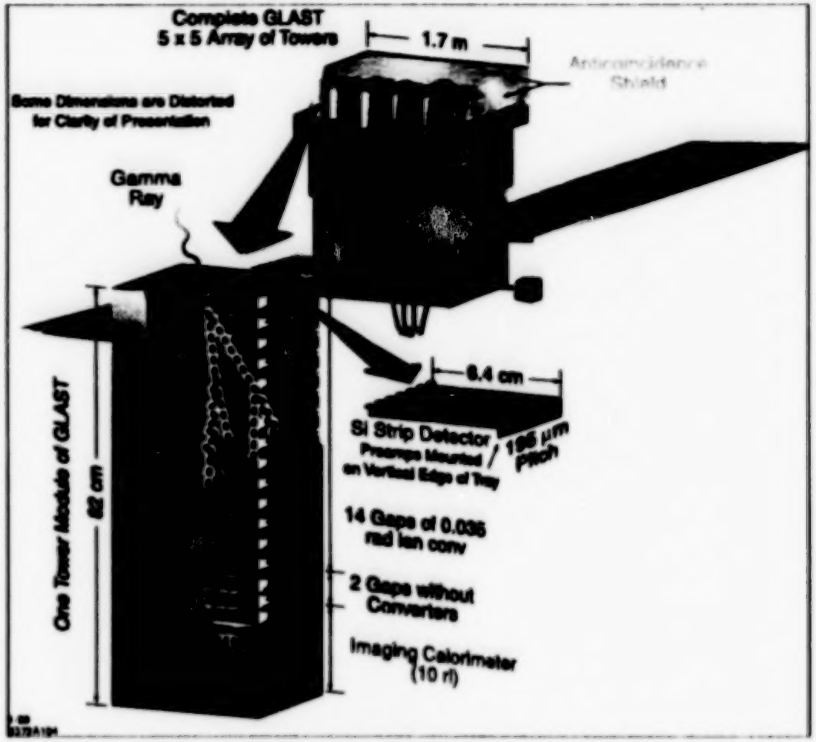
ELEMENT	ACQUISITION METHOD
Instrument Technology	ATD Contracts Ongoing
Instrument and Instrument Operations Center	Announcement of Opportunity Release 6/99
Spacecraft	Rapid Spacecraft Development Office Procurement. RFP Backup
Science Operations Center	NASA Solicitation
Guest Observers	NASA Solicitation
Mission Operations Center And Ground Stations	Consolidated Space Operations Contract

Competing Technologies



Fiber GLAST
U of Alabama is the P.I. organization

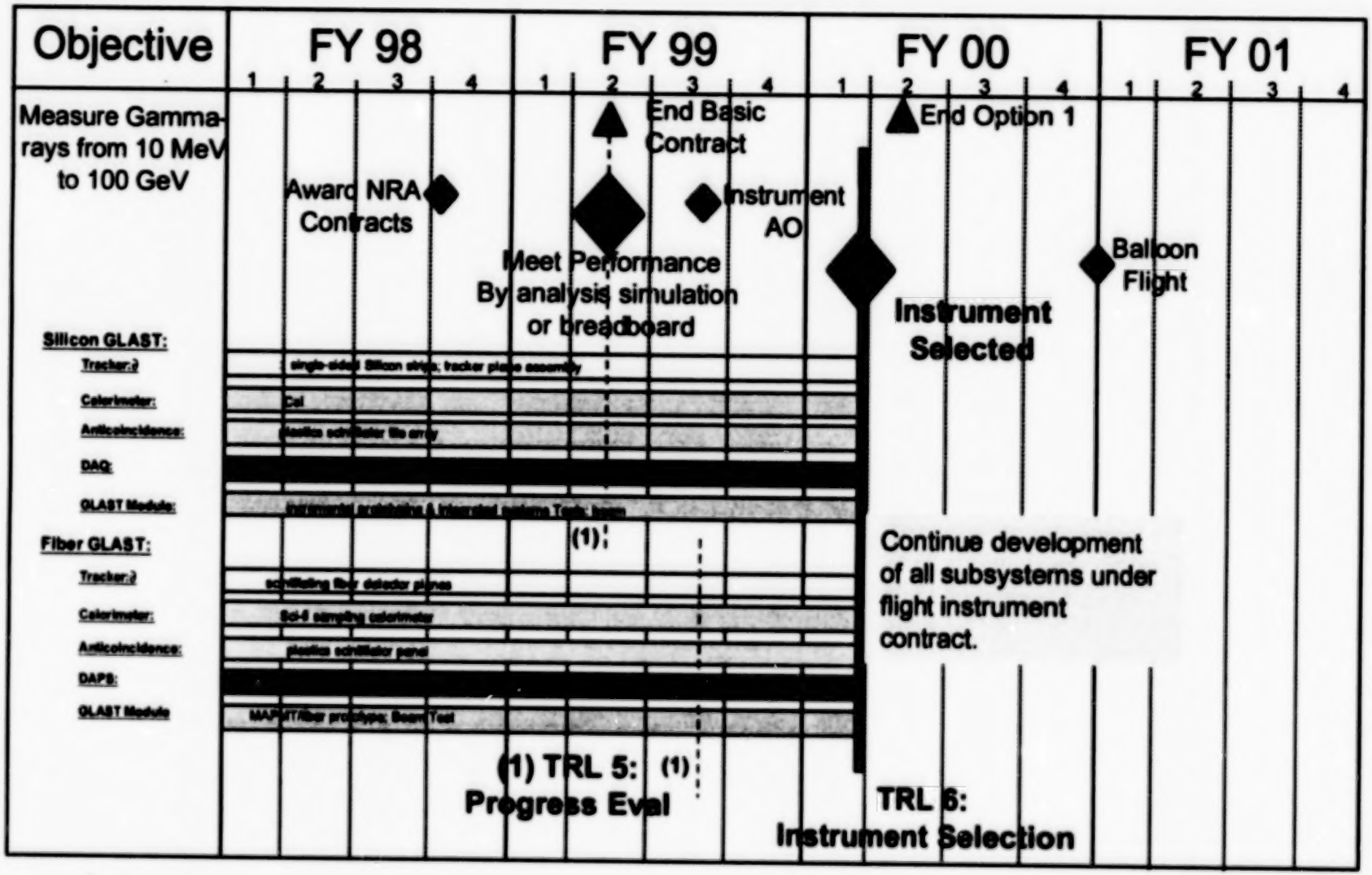
- Tracker is 90 layers of scintillating fibers with tantalum converter.
- Calorimeter is layers of closely packed fibers.
- Anti-coincidence is plastic scintillator panels.
- Data Acquisition and Processing System is centralized, relying on MAPMT's for fiber readout.


Complete GLAST
5 x 5 Array of Towers
1.7 m
Some Dimensions are Distorted for Clarity of Presentation
Gamma Ray
6.4 cm
Si Strip Detector
One Tower Module of GLAST
14 Gaps of 0.035 rad len conv
2 Gaps without Converters
Imaging Calorimeter (10 rl)

Silicon GLAST
Stanford U is the P.I. organization

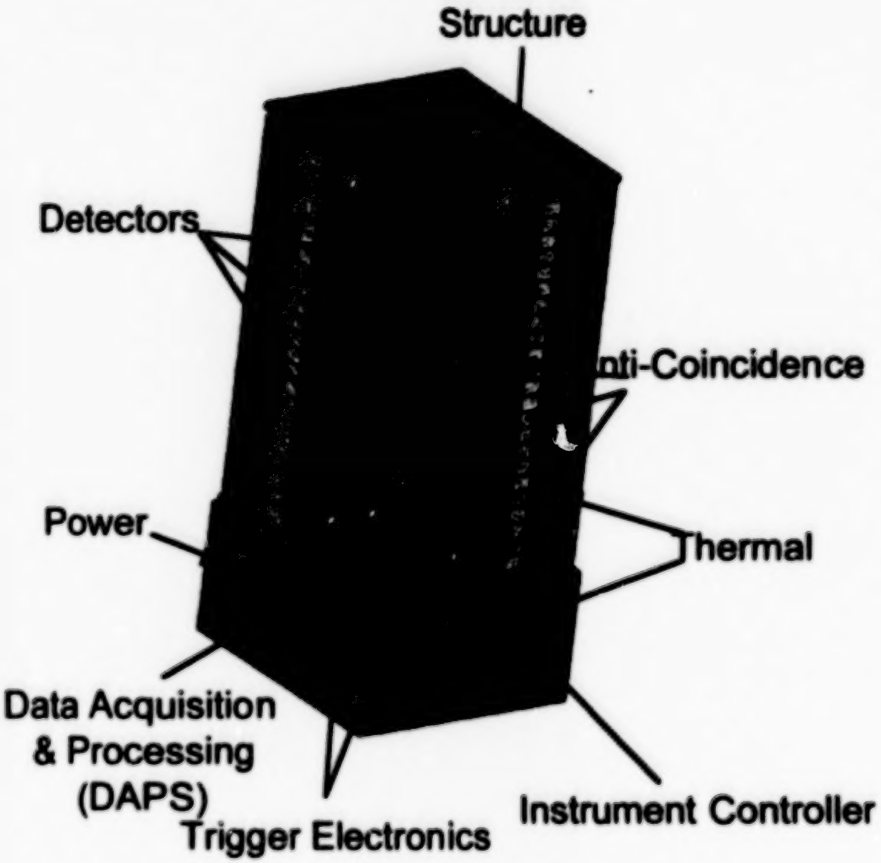
- Tracker technology is layers of Silicon detectors with lead converters.
- Calorimeter is CsI scintillating crystals for energy measurement.
- Anti-coincidence detector is plastic scintillator tiles.
- Data Acquisition System - distributed network with CPU at each tower.
- 25 towers in 5 x 5 array (recently re-baselined to 16 in 4 X 4 array).

Technology Roadmap



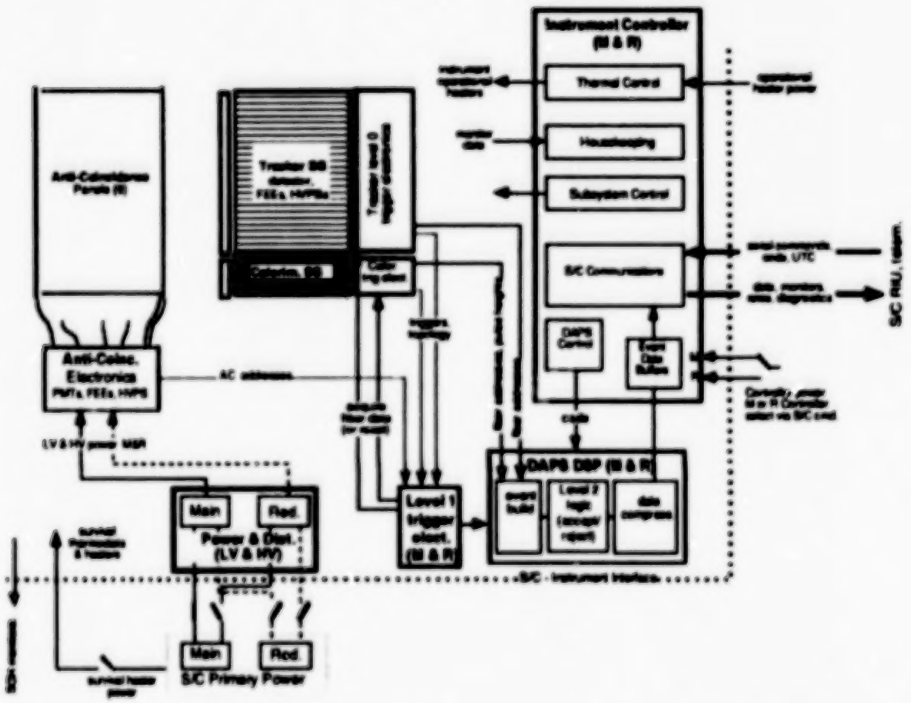
Rev 08/18/98

Progress to Date - Fiber GLAST



System Engineering

- Completed integrated design of subsystems.
- Progress on mechanical, thermal, electrical design of integrated instrument.

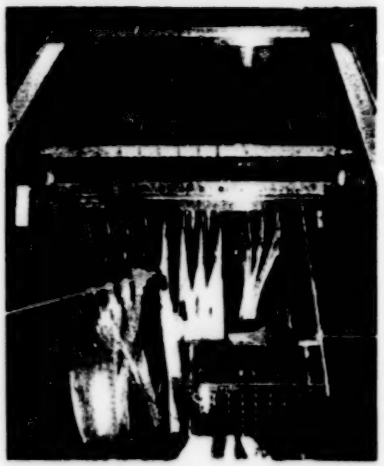


Logical block diagram of integrated system.

Progress to Date - Fiber GLAST

(continued)

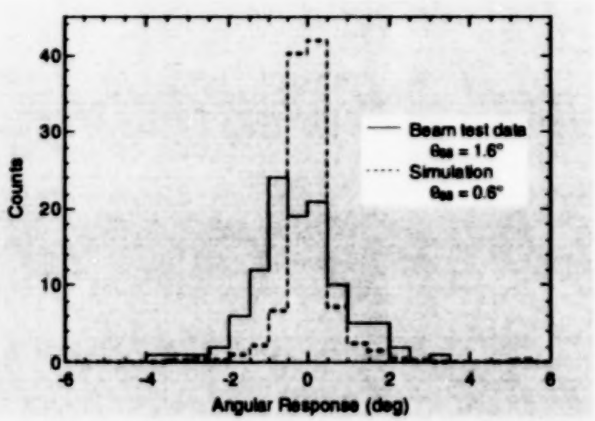
Results of First Beam Test of Fiber/MAPMT System - August 1998



Fiber Planes

MAPMT

- **Proved concept.**
- **Measured 3 different types of fiber configurations.**
- **Angular response measurements were correlated with simulations.**



Correlation of simulation with beam test data for angular response.

Multi-Anode Photo-Multiplier Tubes (MAPMT)

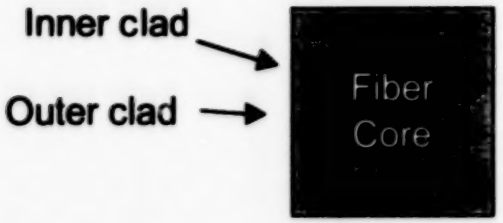
- **Used for Fiber light readout.**
- **Hamamatsu MAPMT has been baselined.**
- **Successfully vibration tested in October '98 - alleviates concern for launch survival.**

MAPMT Mounted for Vibration Testing

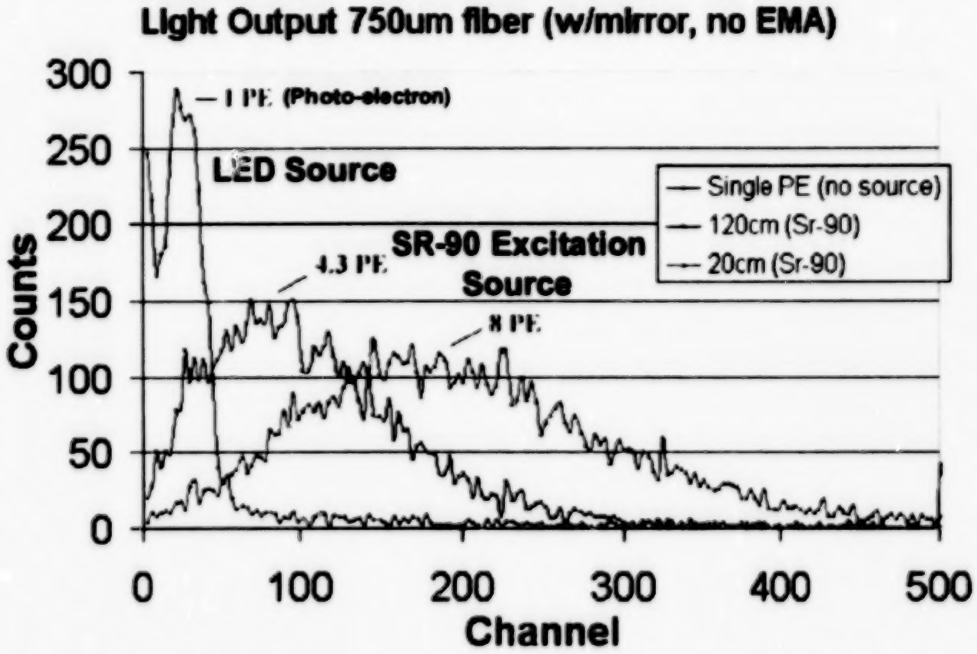
Progress to Date - Fiber GLAST

(continued)

Fibers



Challenge: maximize light output; increase angular resolution (decrease fiber size).
Trade studies completed: size & shape trades; cladding trades; mirror added at end to increase light output; prototype assemblies built.



Number of Fibers & MAPMTs

Detector	#Fibers	Fiber length	#MAPMT's
Tracker	312k	420km	5000
Calorimeter	125k	170km	500-1000
Total	437k	590km	5500-6000

Hamamatsu (MAPMTs) and Bicron (fibers) can meet delivery schedule.

Progress to Date - Fiber GLAST

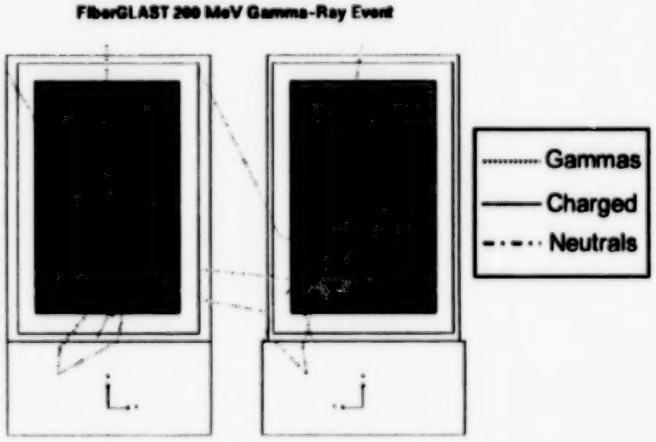
(continued)

Anti-coincidence: Progress on Design: Plastic scintillator panels on 4 sides, top & bottom.

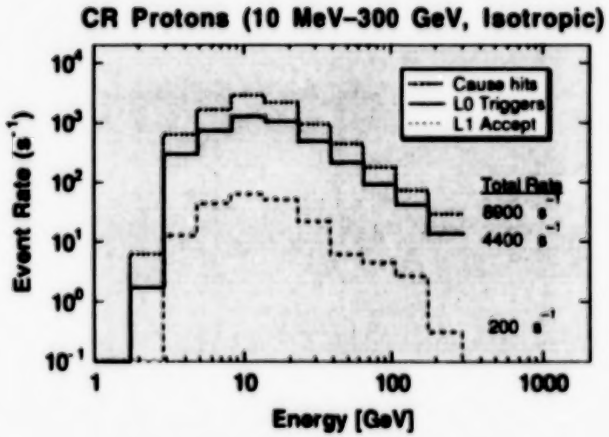
Data Acquisition & Processing System (DAPS): conceptual & physical layout completed, including interfaces with other subsystems.

Trigger & Background Rejection Simulations:

- Trigger algorithm development and hardware design in progress.
- Simulations feedback to design for optimization.
- Simulation database has 7.6 million events at various energies and angles.



Simulated Particle Tracks

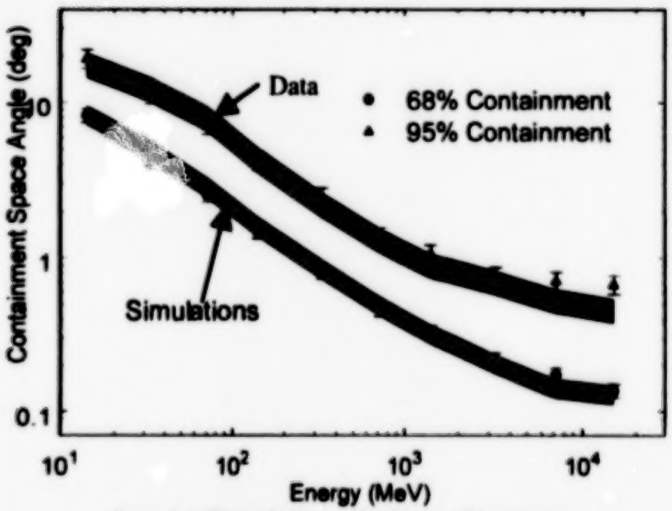


Background Rejection Performance Simulation

Progress to Date - Silicon GLAST

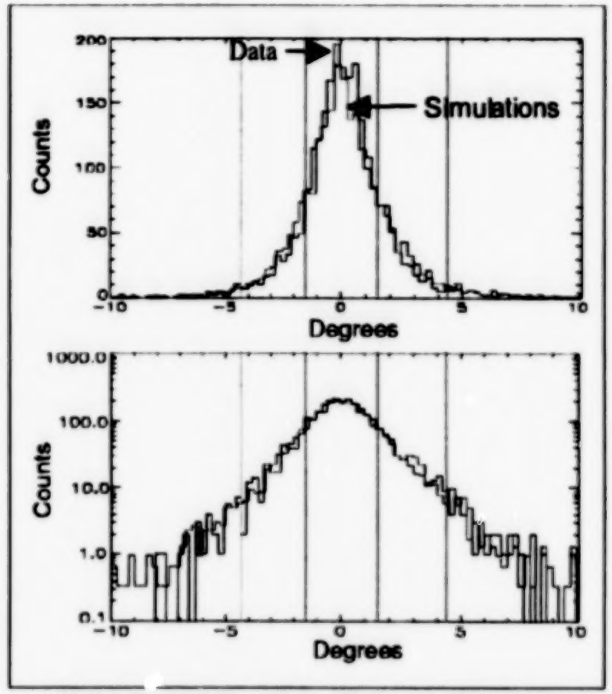
System

- Tower study completed: 4 x 4 array of towers baselined, vs. 5 x 5.
- Mass and power was reduced.
- Detailed structural engineering & integration plans for instrument were developed.
- Prototype tower:
  - Design mostly complete; fabrication in process for fall '99 beam test.
  - Flight-like.
  - 10 stacked trays vibration tested to Delta II levels.
  - Assembly & QC methods developed.
- Independent Reviews: Si detectors, electronics, ACD, DAQ.



Angular Resolution - Data vs. Simulation

Simulations



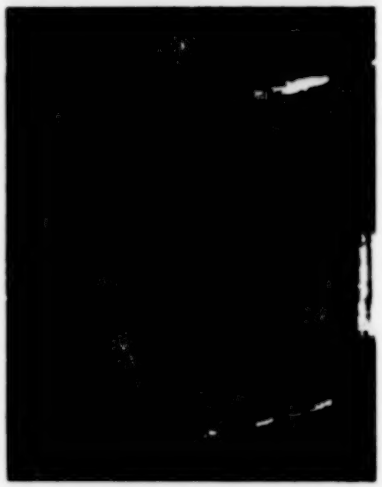
Point Spread Function - Data vs. Simulation

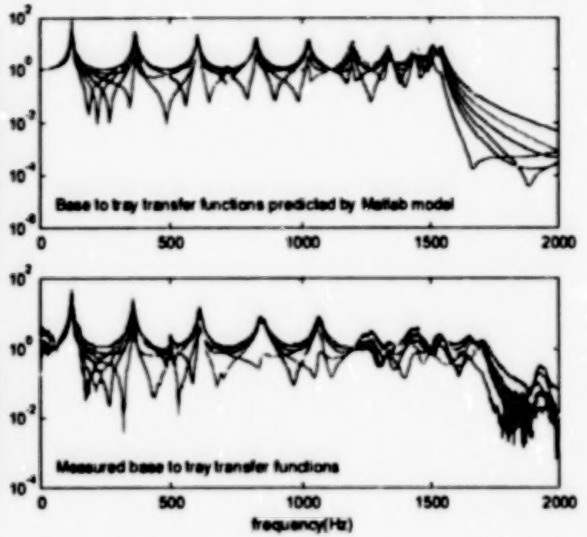
- Completed detailed simulations of:
  - Point spread function (angular resolution).
  - Cosmic ray rejections.
  - Effective area.
  - Trigger analysis.
- Simulations correlated with '97 beam test results.

Progress to Date - Silicon GLAST

(continued)

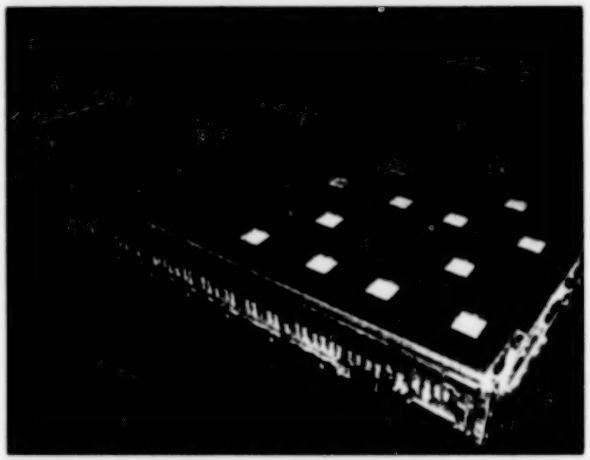
Tracker



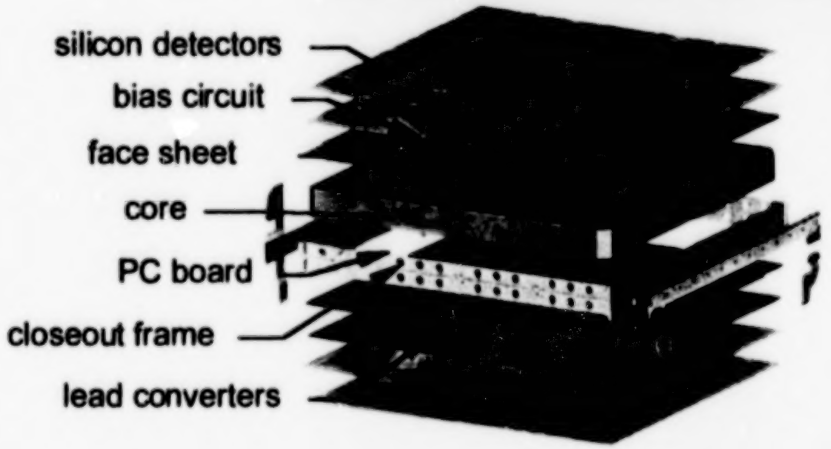


- Detailed mechanical design & dynamics performed.
- Prototype under construction for fall beam test.

- Prototype tray completed.
- 6" wafer technology for silicon detectors.
  - Vendors identified.
- Tracker readout electronics prototype working.
  - Meets all performance & power requirements for flight.



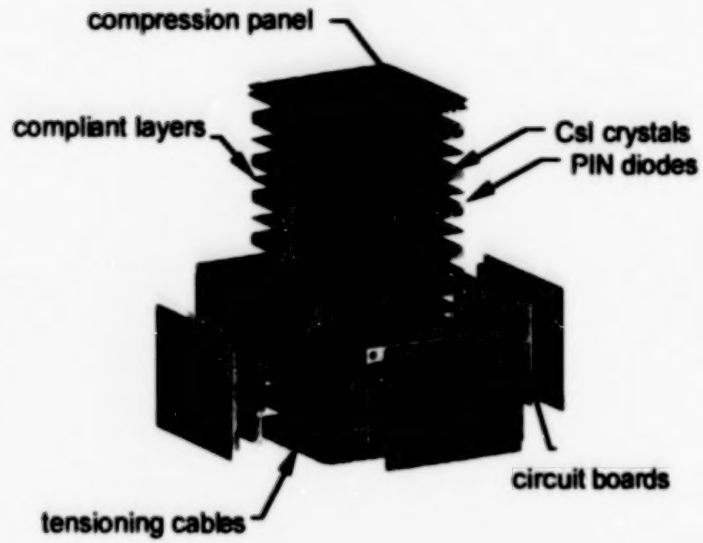
- Detailed tray design nearly completed.
- Study of variable thickness lead converters.



Progress to Date - Silicon GLAST

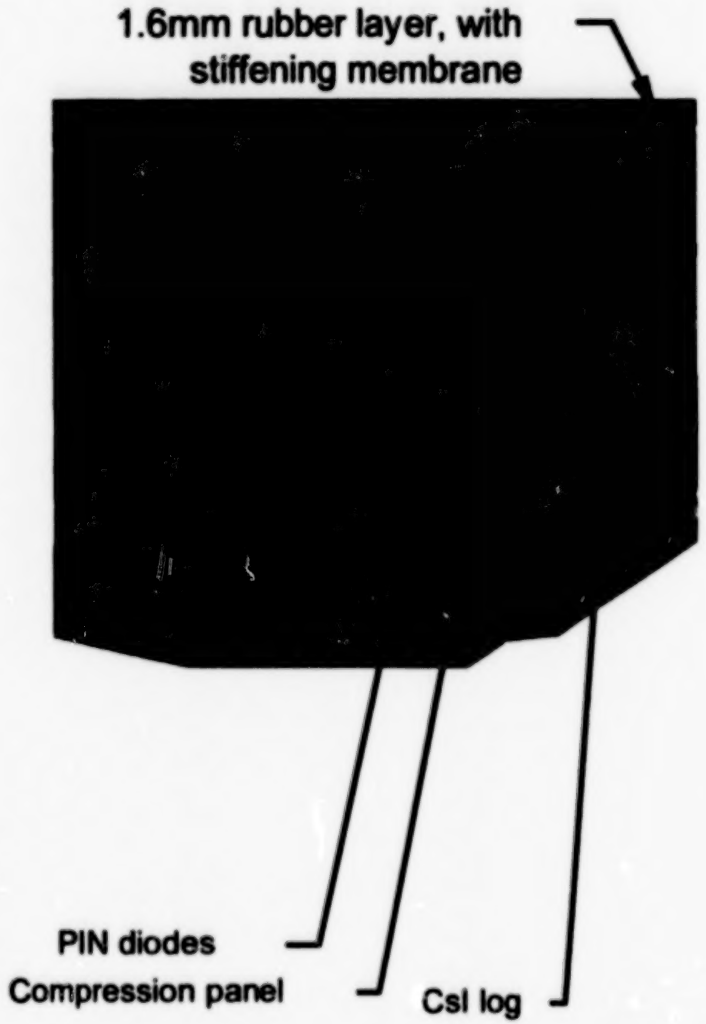
(continued)

Calorimeter



- CsI crystals obtained from Ukraine for testing and prototype tower.
- Detailed mechanical design performed; stops slippage during launch.
- Radiation effects studied.
- Construction of calorimeter structure started for prototype tower.
- Angular, energy resolution results analyzed from '97 beam test.
- 9 trade studies including wrappings, mechanical, dynamic range.
- Front-end ASIC prototype developed.

Compression Cell Design



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Progress to Date - Silicon GLAST

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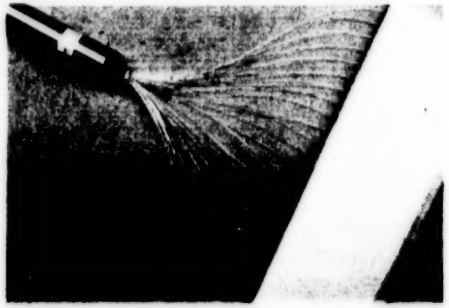
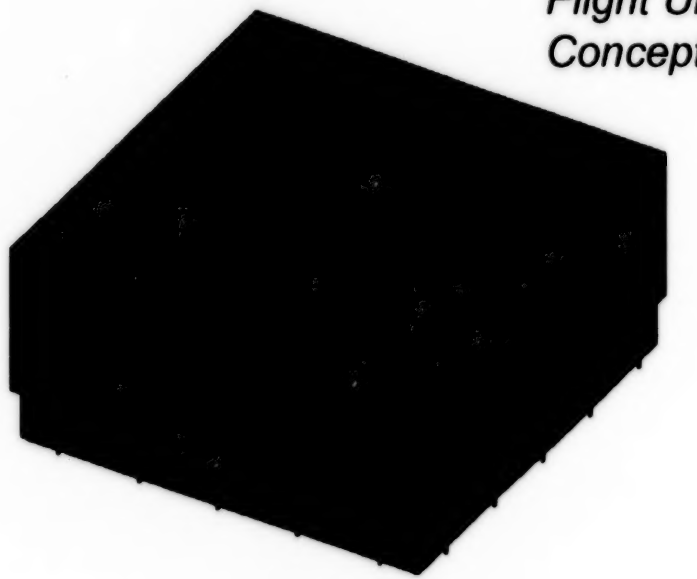


Scintillation Tile w/ waveshifting fiber-PMT readout

Anti-Coincidence Detector

- Plastic scintillator tiles were baselined.
- Detailed mechanical design performed.
- Electronics designed: front-end, trigger interface, DAQ interface.

Flight Unit Concept



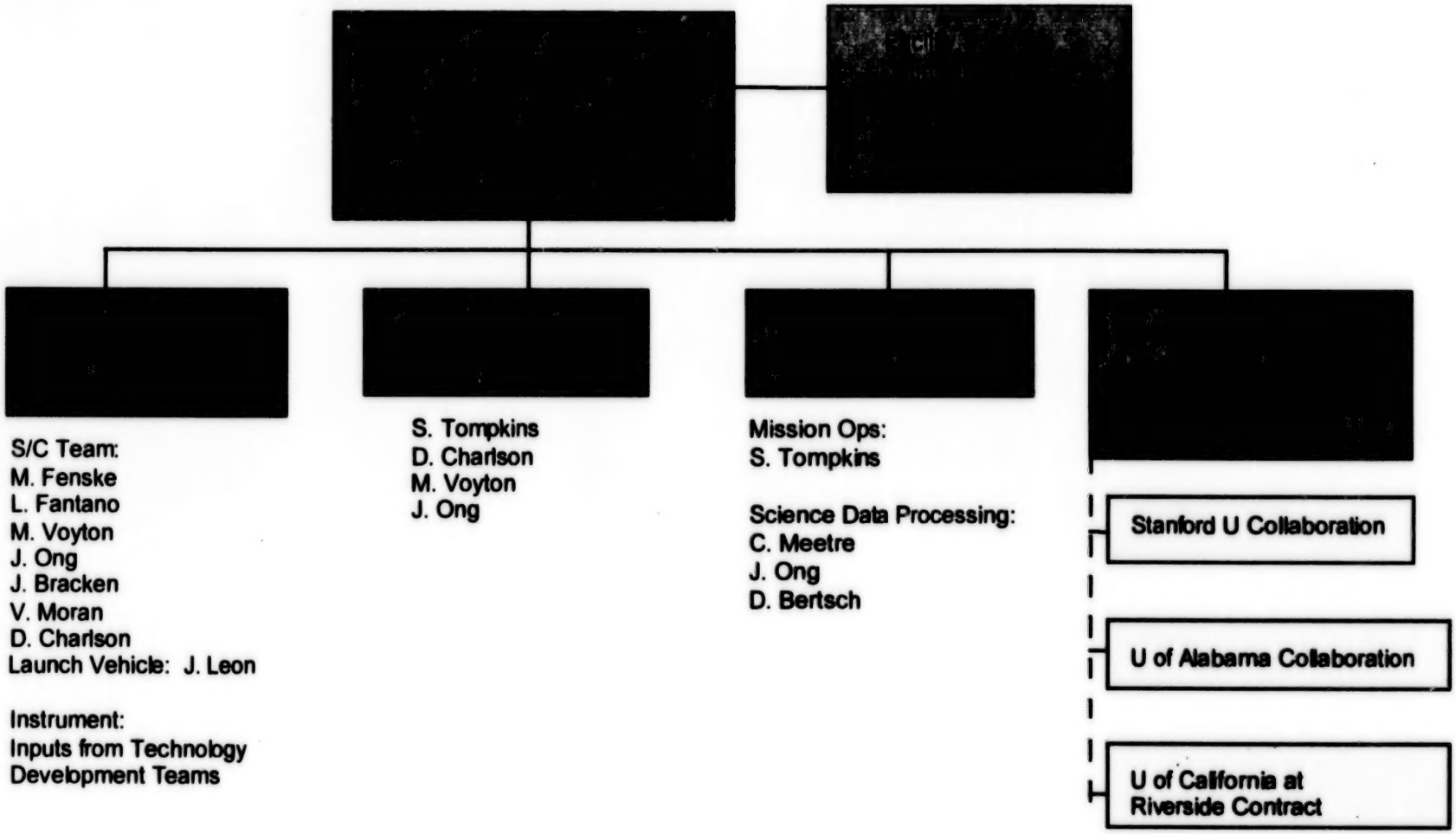
Data Acquisition System (DAQ)

- Low power Data Acquisition System (DAQ).
- 25 identical boards in a 4-way redundant network.
- Completed conceptual design.
- Onboard processing concept developed.
- Prototype VME boards completed and used for testing.

Progress to Date

- **Management**
  - Advanced Technology Development (ATD) contracts started July, 1998: Stanford U and University of Alabama at Huntsville.
  - Basic Reports received in February, 1999; Option 1 exercised.
  - AO in final draft form: target release date June, 1999.
- **Spacecraft/Mission Studies**
  - GSFC's Integrated Mission Design Center (IMDC) conceptual design, modified by Project Team.
  - 3 respondents to RFI for spacecraft concept.
  - Planning with Rapid Spacecraft Development Office (RSDO).
  - Mission studies on launch vehicle, spacecraft, spacecraft-instrument interfaces, mission operations.
- **Meetings/Reviews**
  - Facility Science Team.
    - › Generated Science Requirements Document.
  - Mission Concept Review - September, 1998: Formal review panel at GSFC.
  - GLAST Council.
    - › NASA HQ commissioned: Dr. Mike Turner, chair.
    - › Reviewed Instrument team and program.
  - Outreach: presence at several conferences; brochures, posters, web-site.

GSFC GLAST Team Organization



Instrument Team Organization

Fiber GLAST Collaboration

Dr. Geoffrey Pendleton, PI
U of Alabama in Huntsville

- U of Alabama in Huntsville: Project Mgmt; Simulations; algorithms.
- Washington U: fibers; detector; electronics.
- MSFC: Environmental testing; hardware.
- Louisiana State U: trigger electronics; beam test.
- U. of New Hampshire: System engineering; electronics; management.
- U. of Calif, Riverside: ASIC's.
- NOVA R&D, Inc: ASIC's.
- Other potential industry partners.

Silicon GLAST Collaboration

Dr. Peter Michelson, PI
Stanford U

- Stanford U: Management; mechanical/system engineering; electronics; simulations.
- DOE/SLAC: partnering with NASA; management; mechanical/system engineering; electronics; simulations.
- NRL: calorimeter; data acquisition system; software.
- GSFC: anti-coincidence detector, electronics, software, simulations.
- U of Calif, Santa Cruz: tracker, software.
- U of Washington: software.
- International:
  - France, Sweden: calorimeter
  - Japan, Italy, U.K.: tracker

GLAST Budget Requirements

Current POP Guidelines (RY$M)

New Start

	1997	1998	1999	2000	2001	2002	2003	2004	2005	06-10	Total
All Phases (Launch Vehicle Included)	0.80	3.32	4.85	4.85	8.73	16.49	76.25	109.00	37.18	64.90	326.37

Project Preferred Profile (RY$M)

	1997	1998	1999	2000	2001	2002	2003	2004	2005	06-10	Total
Formulation	0.80	3.32	4.85	4.85	8.73						22.55
Implement/Develop.						31.32	53.35	67.29	25.60		177.56
Launch Vehicle							22.9	26.88	11.58		61.36
Implement/MO&DA										64.90	64.90
GLAST Total	0.80	3.32	4.85	4.85	8.73	31.32	76.25	94.17	37.18	64.90	326.37

Assumption: DOES NOT include full cost accounting.

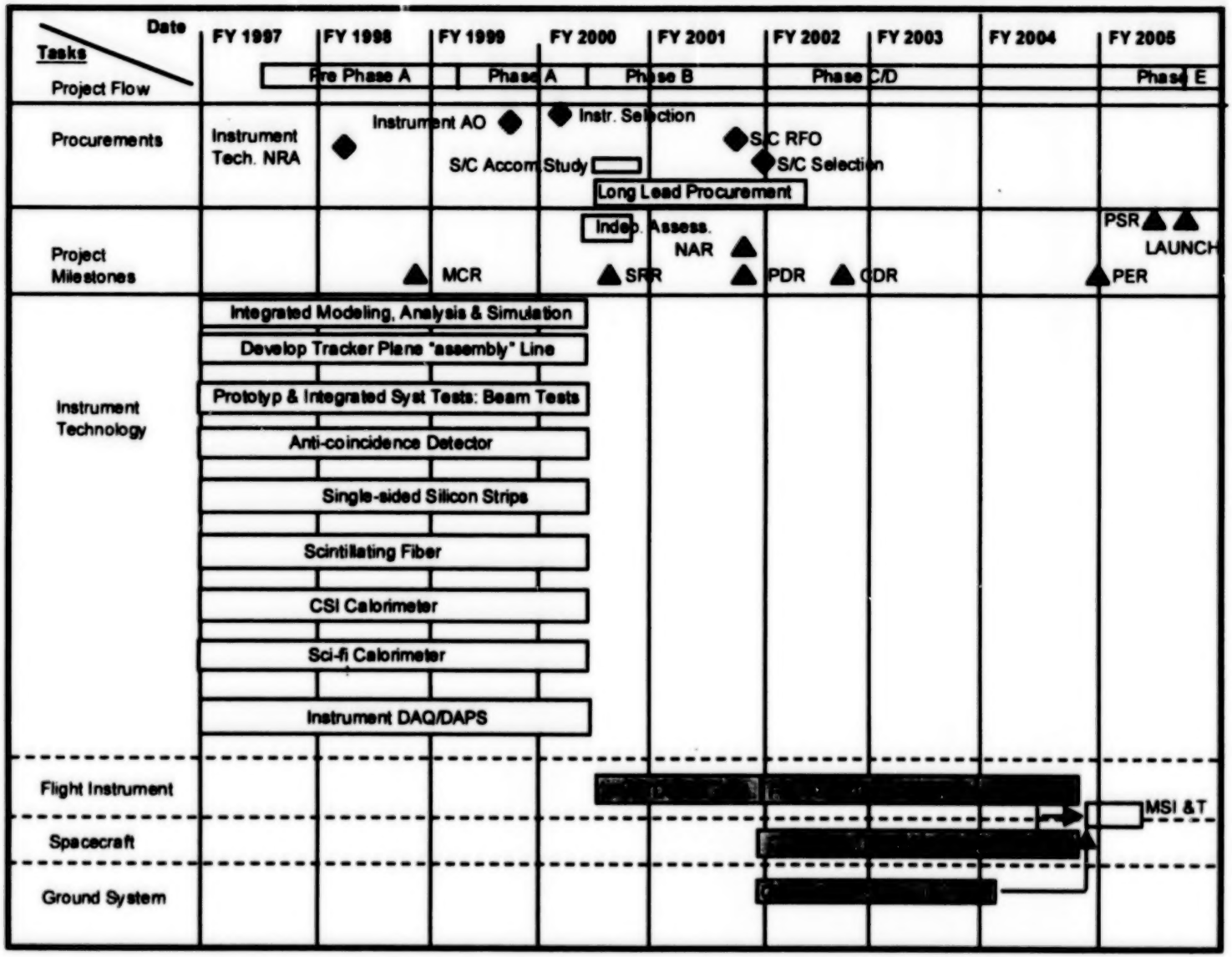
Contributions Assumed:

Fiber GLAST: No Non-NASA contributions

Silicon GLAST: DOE = Approx. $20M+ salaries; France = approx. $20M; Japan = $5 -10M; Sweden = $5M; UK = under discussion; Italy = under discussion.

Issue: Shortfall in FY02 means launch slip from 6/05 to 12/05 and reduced contingency.

Mission Schedule Overview

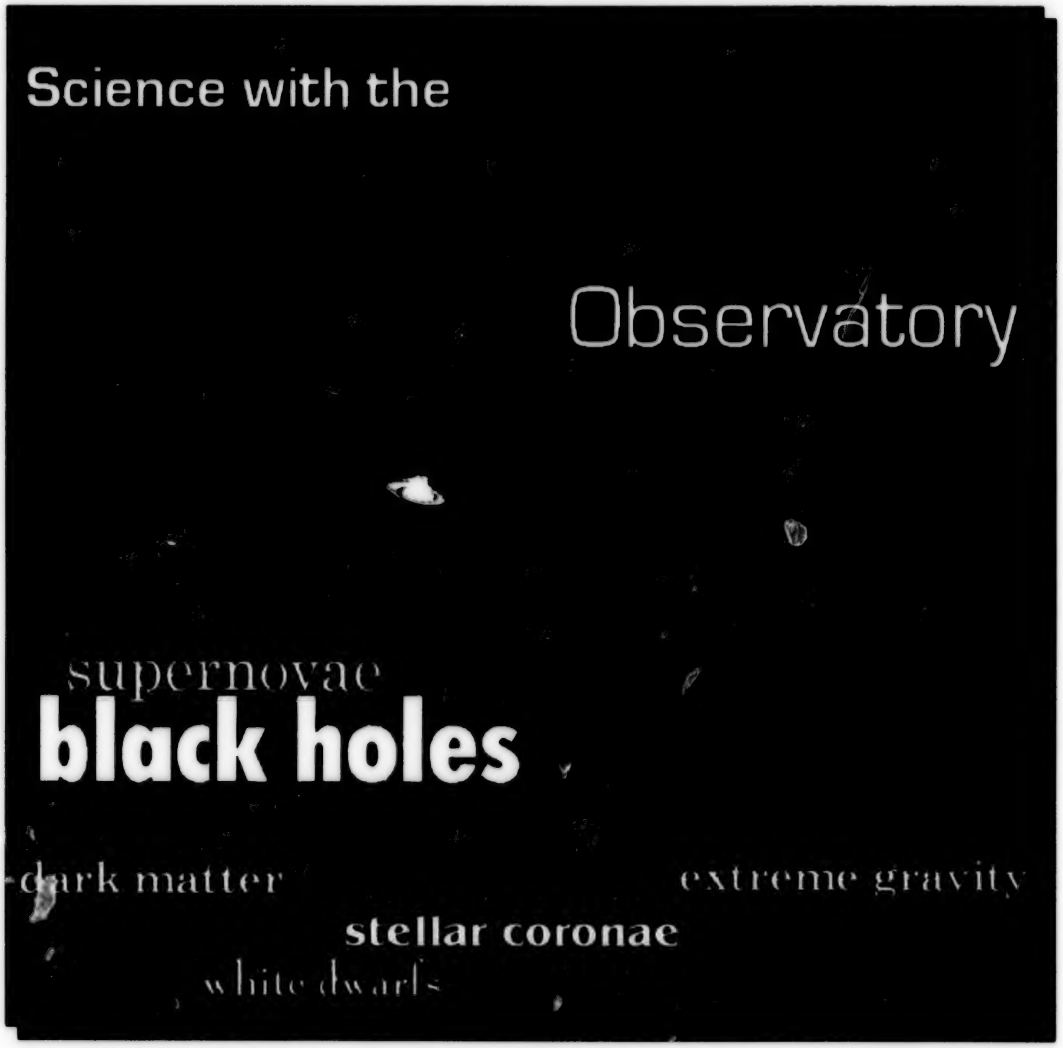


Revised 04/22/99

Outlook

- **One year from now:**
  - Flight Instrument selected and on-board
    - › Partnerships in place; Project-Instrument developers working as a team.
    - › '99 Beam tests completed with prototype hardware
    - › Organizations committed; roles defined; budget sources verified.
  - System Requirements Review completed.
  - Independent Assessment in process.
  - Spacecraft Accommodation Studies in process.
- **Five years from now:**
  - Three months before instrument delivery to spacecraft manufacturer for I&T.
  - Instrument in final assembly, testing, and calibration.
  - Spacecraft in final assembly and testing.
  - Science community, public and Congress looking forward to results, due to outreach activities.

Constellation X-ray Mission



Jean Grady
Goddard Space Flight Center
http://constellation.gsfc.nasa.gov

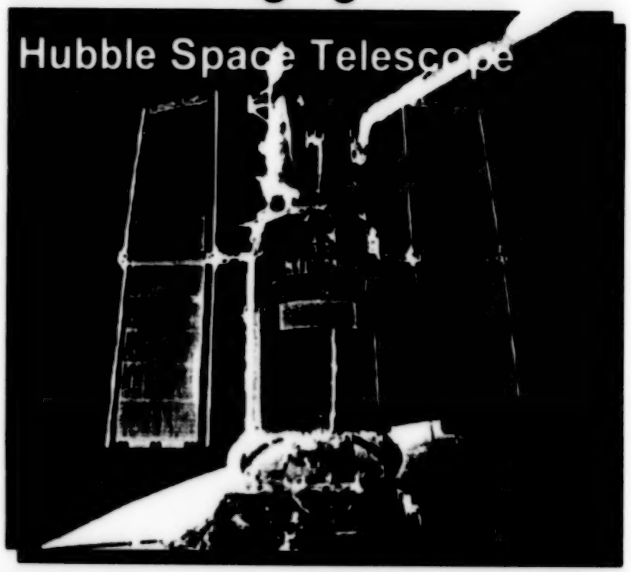
The Constellation X-ray Mission

- **Constellation-X is X-ray astronomy's equivalent of the Keck telescope**
  - Effective area: 15,000 cm^2 at 1 keV
    - › 100 times Chandra and XMM for high resolution spectroscopy
  - Spectral resolving power: 3,000 at 6.4 keV
    - › 5 times Astro-E calorimeter
  - Band Pass: 0.25 to 40 keV
    - › 100 times more sensitive than Rossi XTE at 40 keV

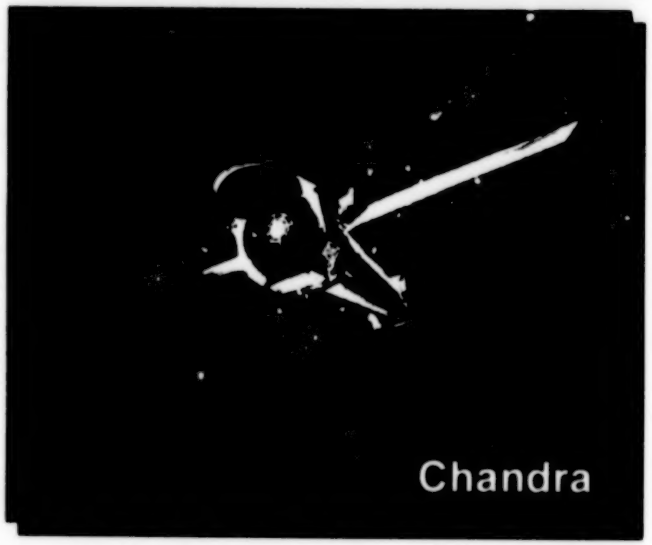
- **Highlights from past year**
  - Revised GSFC/SAO reference mission configuration from six to four spacecraft
    - › Results of EELV procurement, consistent with expectations
    - › Minimizes launch cost
  - Completed mission configuration studies by Ball and TRW (Cooperative Agreement Notice)
  - Developed independent cost estimates
  - Fabricated light weight 0.5 meter pathfinder shell for X-ray optics from new nickel alloy
  - Demonstrated significant improvement in X-ray calorimeter energy resolution, within factor of two of requirement
  - Achieved higher resolution, lower noise on CdZeTe detectors

X-ray Equivalent of the Keck Telescope

Imaging



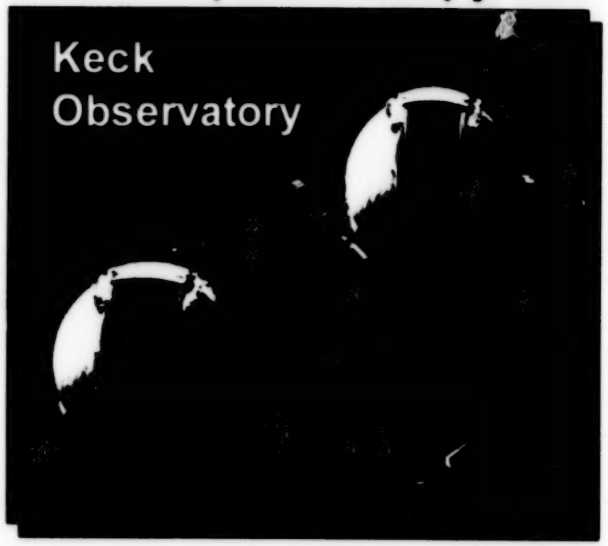
0.1 arc sec
40,000 cm²



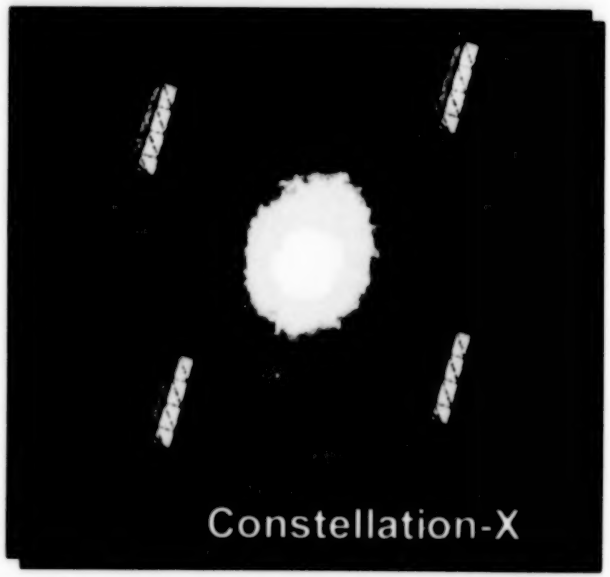
0.6 arc sec
1,000 cm²
(100 cm²)*

* effective area at the spectrometer

Spectroscopy



≤1 arc sec
780,000 cm²

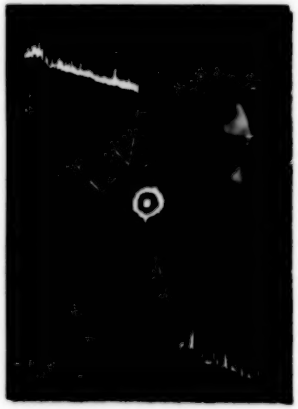


≤15 arc sec
30,000 cm²
(15,000 cm²)*

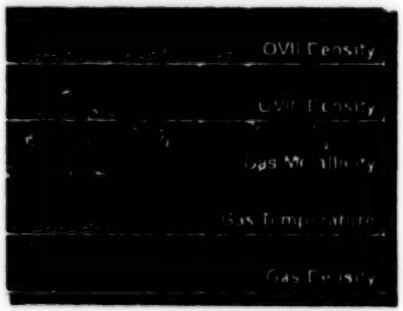
Science Overview

Constellation-X will address key questions to understanding the Universe

- **Can supermassive black holes be used to test General Relativity?**
  - Probe close to event horizons to observe effects of General Relativity in the strong gravity limit
  - Determine black hole spin and mass from broad iron line

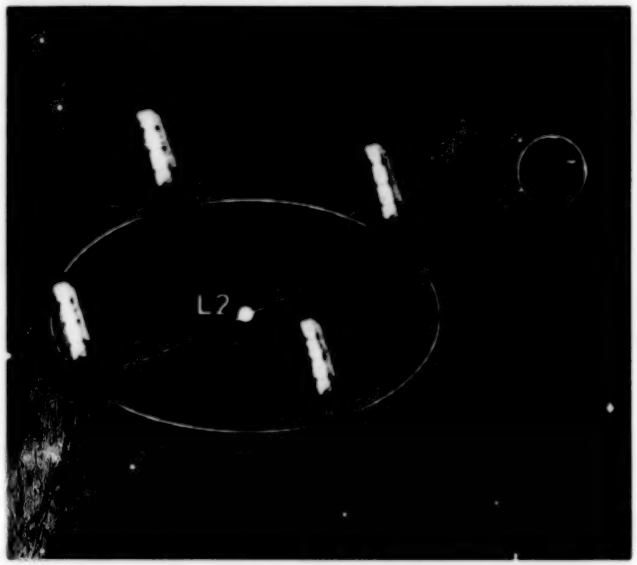


- **When did clusters of galaxies form and how do they evolve?**
  - Determine epoch of cluster formation and trace its evolution
  - Measure elemental abundance of 25 elements including Carbon, Oxygen, Silicon, and Iron
  - Map cluster mergers and cooling flows



- **Where are the "missing baryons" in the local universe?**
  - Detect baryons in the hot IGM via absorption lines they produce in spectra of background quasars
  - Observe the local Lyman alpha forest

Constellation-X Mission Concept

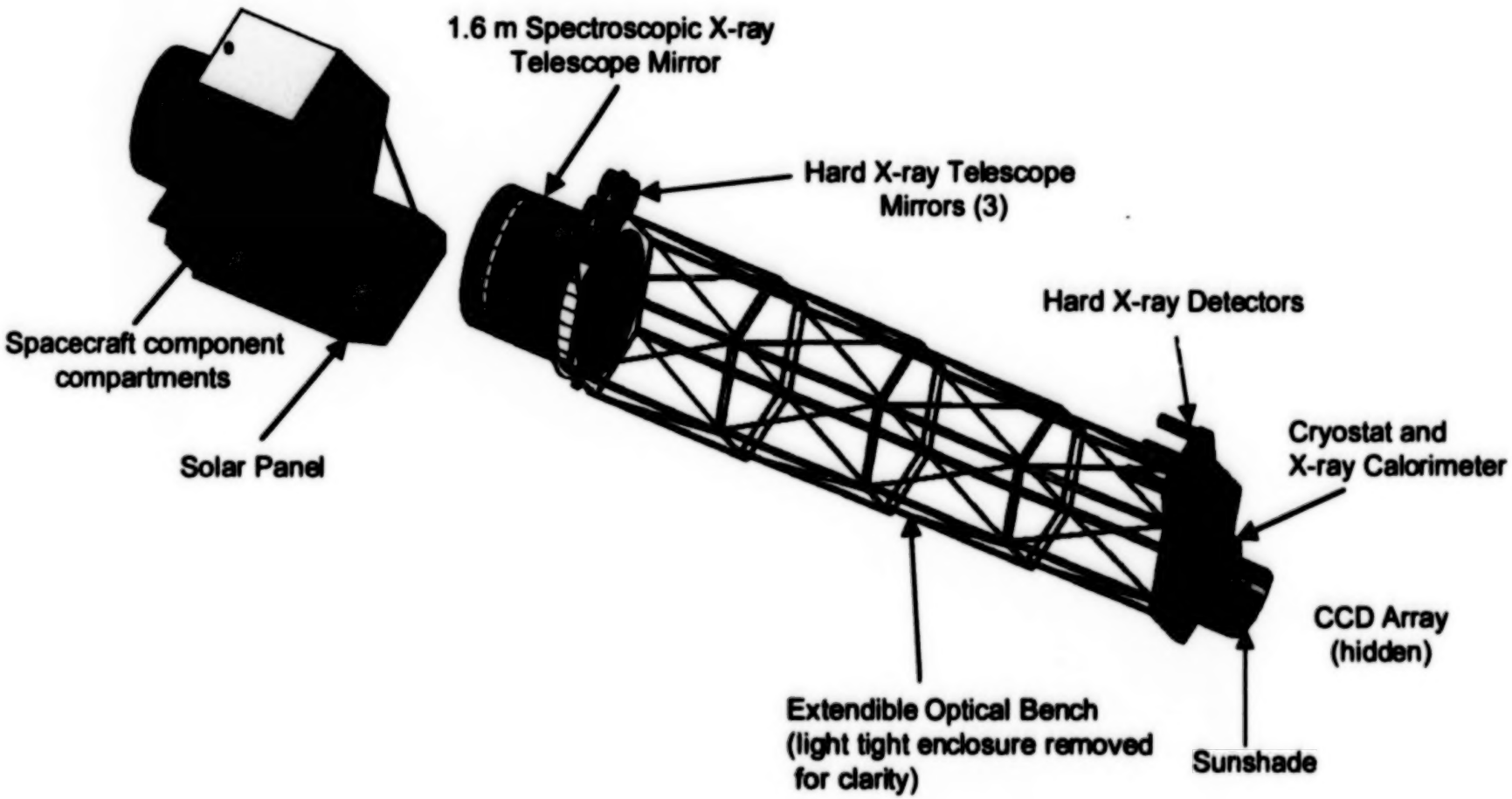


- **A multiple satellite approach**
  - To achieve 30,000 cm^2 aperture on a single satellite requires a Titan-class launch
  - An alternative low-risk approach utilizes a constellation of multiple identical low-cost satellites; each carries a portion of the total effective area
  - Simultaneous viewing and high efficiency facilitated by using libration point orbit

- **Baseline configuration:**
  - Four satellites, launched two at a time on Atlas V or Delta IV
  - Extendible optical bench is used to achieve a focal length of 10 m yet allows two satellites to be packaged on a single launch vehicle
  - Modular design allows:
    - Parallel development and integration of instrument module and spacecraft bus
    - Low cost standard bus architecture and components

Reference Design

(GSFC/SAO)



CAN Mission Configurations

- **Successfully completed mission concept studies under Cooperative Agreement Notice (CAN) by Ball and TRW by December 1998.**
- **Two different technically feasible approaches complement GSFC/SAO approach.**
- **These studies provided independent cost estimates.**

Ball Baseline Configuration

- **Two satellites, each fully redundant**
- **Three 1.3 m SXTs plus 9 HXTs per satellite**
- **Fixed optical bench**
- **Separate cold and warm ends to design**
- **Requires two EELVs**

TRW Baseline Configuration

- **Three satellites**
- **Two 1.3 m SXT plus four HXTs per satellite**
- **Extendible optical bench**
- **Simple s/c bus based on existing designs**
- **Requires three EELVs**

Constellation-X Requirements Flow Down

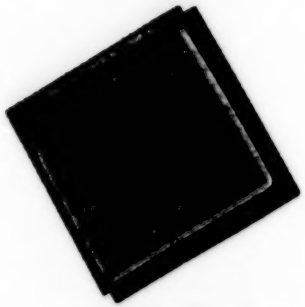
Science Goals	Measurement Capabilities	Engineering Implications	Key Technologies
Parameters of Supermassive Black Holes Elemental Abundances and Enrichment throughout the Universe Plasma Diagnostics from Stars to Clusters	**Minimum effective area:** **SXT** 15,000 cm_ at 1 keV 6,000 cm_ at 6.4keV **HXT** 1,500 cm_ at 40 keV **System Angular Resolution and FOV** **SXT** 15" HPD FOV >2.5' **HXT** 1' HPD FOV >8' **Minimum spectral resolving power (E/DE):** **SXT** 300 from 0.25 to 6.0 keV 3000 at 6 keV **HXT** >10 at 40 keV **Band Pass:** **SXT** 0.25 to 10 keV **HXT** 6 kev to 40 keV	**Minimum Effective Area:** • Light Weight Optics (<250 kg.) • Extendible Optical Bench (8-10 m) **System Angular Resolution and FOV:** • Tight tolerances on telescope figure, surface finish, alignment • ±1 °C temp. control on mirror assembly • Requires ≥ 30 x 30 array for microcalorimeter (pixels ~5") • Cryocooler requirements driven by array size and readout electronics **Resolving Power:** • Dispersive *and* non-dispersive capability to cover SXT band • Dispersive performance tied to telescope resolution **Band Pass:** • 2 types of telescopes needed to cover energy range	**High Throughput Optics** • High performance replicated shells and segments • coatings and layers • High strength/mass materials for optical surfaces **High Spectral Resolution** • 2 eV microcalorimeter arrays • Coolers • Lightweight gratings • CCD arrays extending to 0.25 keV **Broad Bandpass** • Multilayer optics • CdZnTe detectors **Extendible Optical Bench** • Stable (vs. time and temp.) • High strength/low weight materials

Constellation-X Technology

Approach

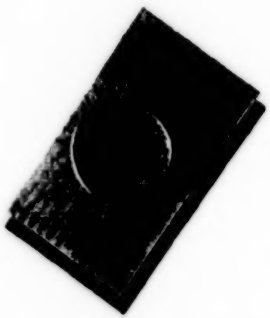
- **Extension of demonstrated technology**
- **Parallel path technology development with defined selection milestones**
- **Synergism within program activities, e.g., SXT and HXT optics**
- **Leverages other technology investments:**
  - Cross-enterprise technology, e.g., Cryocoolers
  - SBIR, e.g., optics
  - SR&T, e.g., CdZeTe detectors

Lightweight X-ray Optics

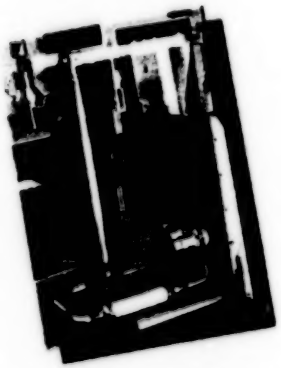


CdZnTe Arrays

Multilayer Coatings

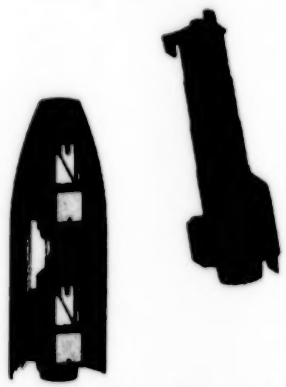


X-ray Calorimeters



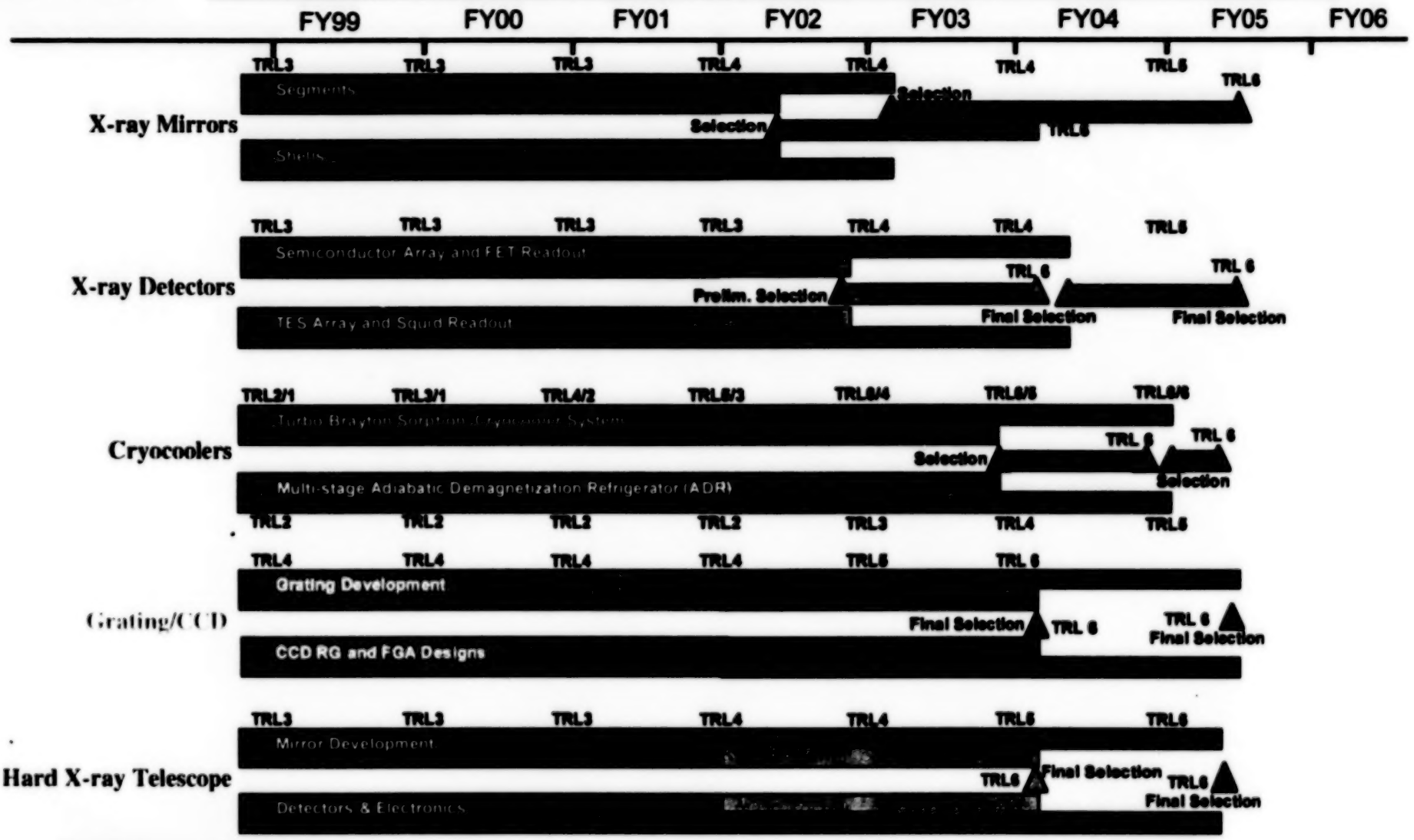
Cryocoolers

CCD/Gratings



Deployable Structures

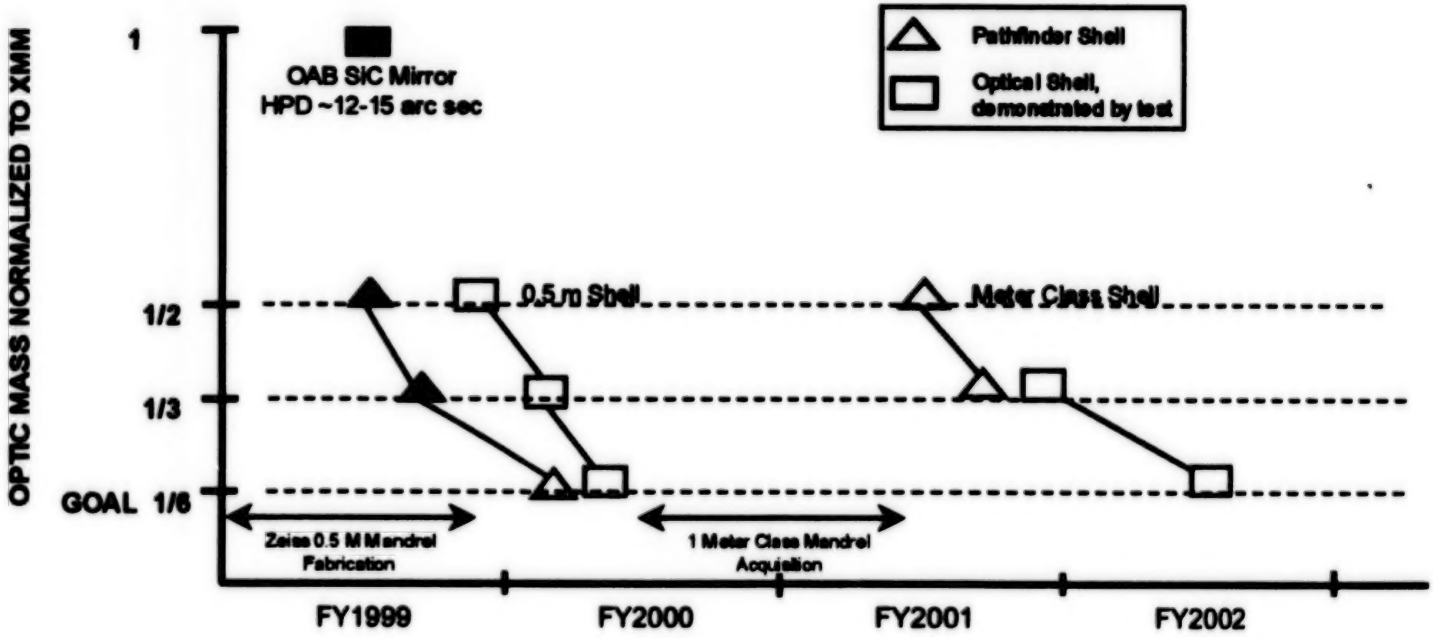
The Constellation-X Technology Roadmap



SXT Replicated Shell X-ray Mirrors

- **Goal is to show feasibility of 1.6m replicated shell mirror with normalized weight 1/6 of XMM mirror and Half Power Diameter (HPD) of <10 arc sec**

0.5m Shell

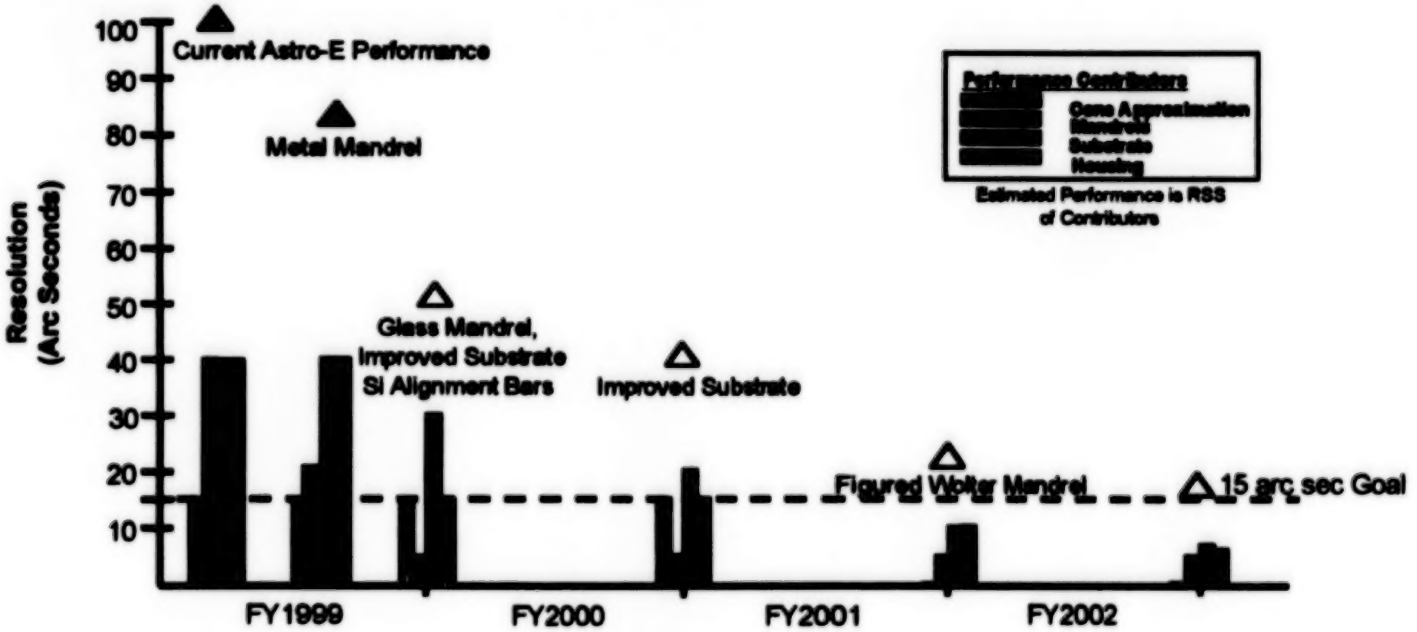


- **Progress**
  - Developed infrastructure for manufacturing and metrology of large X-ray optics
  - Developed high performance electro-formed nickel alloy
    - Micro-yield order of magnitude higher than pure nickel
    - Fabricated 0.5 m pathfinder shell and demonstrated shell separation
    - 0.5 m optic for X-ray testing in process
  - Silicon Carbide (SiC)
    - OAB manufactured SiC mirror with HPD ~12-15 arc sec
- **Partnership: MSFC/SAO/OAB**

SXT Segmented X-ray Mirrors

- **Goal is to show feasibility of a 1.6 m replicated segment mirror having a normalized weight of 1/6 XMM and a system HPD of 15 arc sec**
  - Segmented approach already meets weight requirement

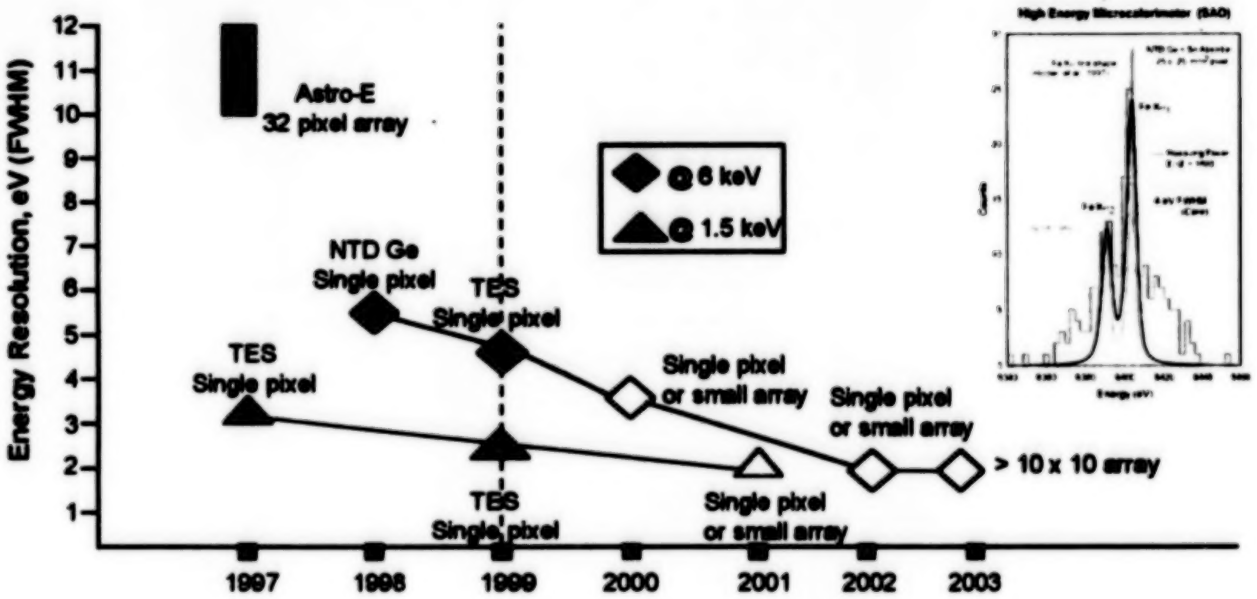
Etched Silicon Alignment Bar

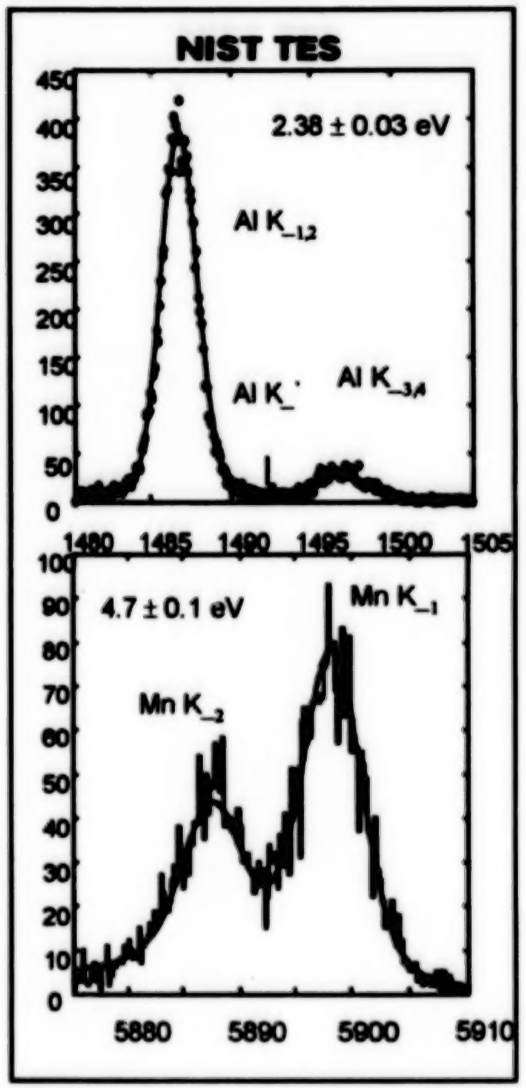


- **Progress**
  - Metal mandrel improved mandrel figure by factor of 2 over Astro-E
  - Glass mandrel, to be delivered June 1999, will improve mandrel figure by an additional factor of 4
  - Designed and fabricated ultra-precise alignment bars using silicon etching technology
- **Partnership: GSFC/MIT/SAO/RJHS**

X-ray Calorimeters

- **Needed: 2 eV FWHM from 1 to 6.9 keV at 1000 counts/s/pixel in 30 x 30 array**
- **Parallel Approach: TES and NTD/Ge Calorimeters**

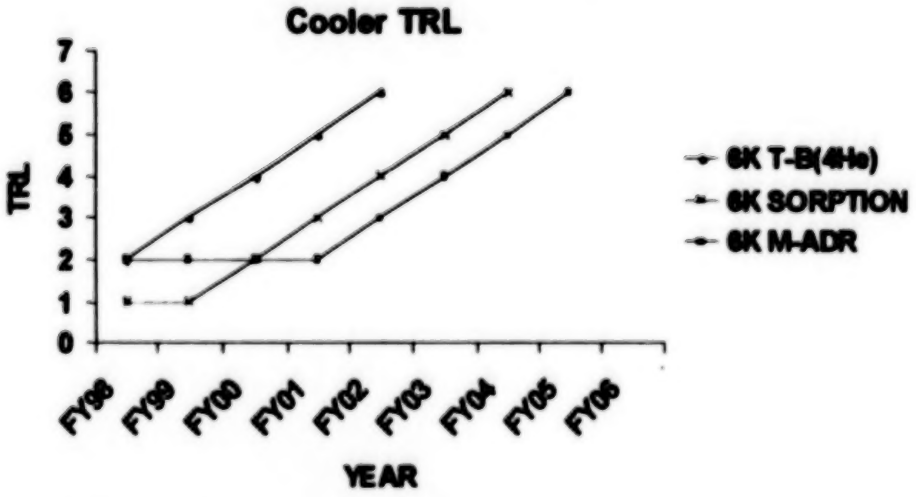


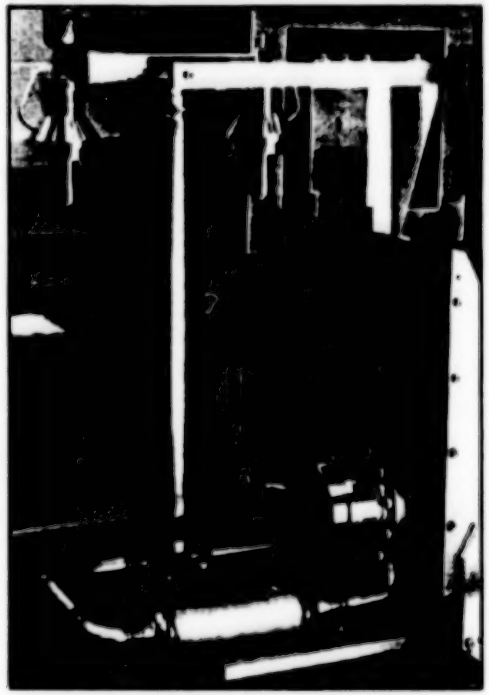


- **Progress:**
  - Achieved 2.4 eV at 1.5 keV and 4.7 eV at 6 keV!
  - Identified robust materials for TES thermometer
  - Fabricated and analyzed pop-up Si array structures for TES
  - Demonstrated technique for cantilevering TES absorbers
  - Manufactured a 16-element NTD/Ge array
  - Demonstrated techniques for multiplexing
- **Partnership: GSFC/NIST/SAO/UW/LLNL/Stanford**

Cooling Systems for X-ray Calorimeter

- **Requirement: Long life cooling systems that provide 40 - 65 mK to calorimeter**
- **Parallel Approach: Turbo-Brayton or Sorption cooler to 4 - 8 K with multi-stage ADR**
- **Progress:**
  - Turbo-Brayton
    - 70 K cooler was successfully flown on HOST Shuttle mission
    - 65K cooler completed 3 year endurance test
    - Completed cold bearing tests on 35 K cooler; 10K tests planned for 1999
    - 4-10K breadboard being fabricated for test in late1999
  - Sorption cooler
    - 6K breadboard planned for 2002
- **Require funding for multi-stage ADR development**





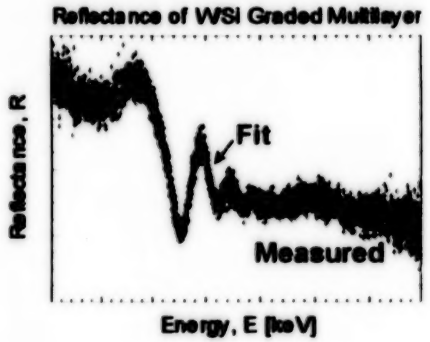
HOST Cooler

- **Partnership: GSFC/JPL/Creare**

Hard X-ray Telescope

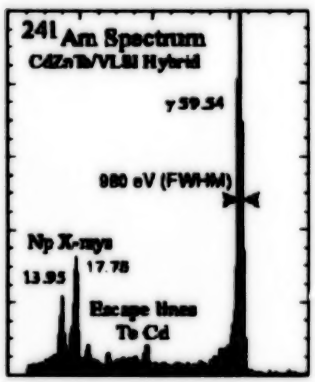
HXT Optics

- **Requirements: High reflectivity from ≤ 6 to ≥40 keV with 1 arc min. HPD over an 8 arc min. FOV**
- **Completed opto-mechanical breadboard of thermally-formed glass microsheet optics**
  - 40 arc sec HPD figure for mounted shells
  - High-throughput segmented optic mounting technique
- **Multi-layer development**
  - Measured reflectance corresponding to 2.5A interface widths for complex 300 layer W/Si coating
  - Demonstrated stability of Pt/C multilayers

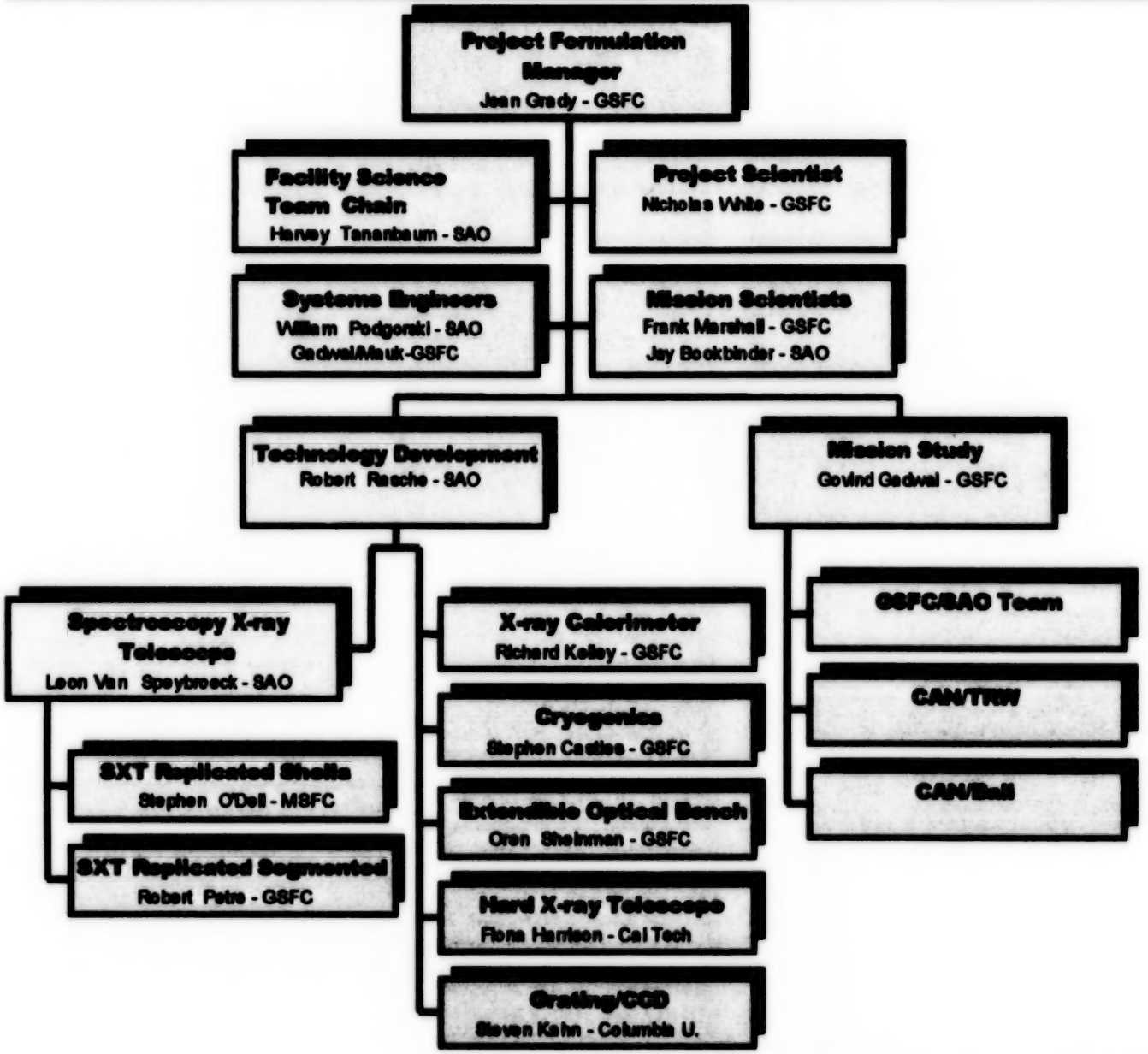


Detectors

- **Requirements: Low threshold (≤6 keV), large format (~1 in. x 1 in.) with high QE**
- **Demonstrated new, custom, low-noise ASIC/CdZnTe detector**
  - 980 eV FWHM (60 keV) - factor of 3 improvement over any existing pixel detector
  - 2 keV threshold - factor of 5 improvement over any existing pixel detector
  - Required improvements: reduce pixel size 20%, reduce noise factor 2
- **Successful selection of near-perfect 1 in. x 1 in. CdZnTe sensors**
  - Demonstrated high yield from commercial product using new characterization and screening facility
- **Partnership: CalTech/GSFC/Columbia U./MSFC/Harvard/SAO/NW/NRL**



Organization



In-guide Budget through FY 2005
(with 2000/2001 Re-phased)

	Prior	FY99	FY00	FY01	FY02	FY03	FY04	FY05	Total
Technology Development	4.2	1.3	1.3	1.3	4.1	4.2	18.3	7.7	42.4
Mission Formulation	1.0	0.3	0.3	0.3	0.6	0.8	4.7	2.8	10.8
Phase B								26.5	26.5
Total	5.2	1.6	1.6	1.6	4.7	5.0	23.0	37.0	79.7

Guidelines		1.6	1.6	1.6	4.7	5.0	23.0		
Cross-enterprise and SBIR		1.4	TBD	TBD					
SEU Science DDF		0.5	0.4	0.4					
Total-All Sources		3.5							

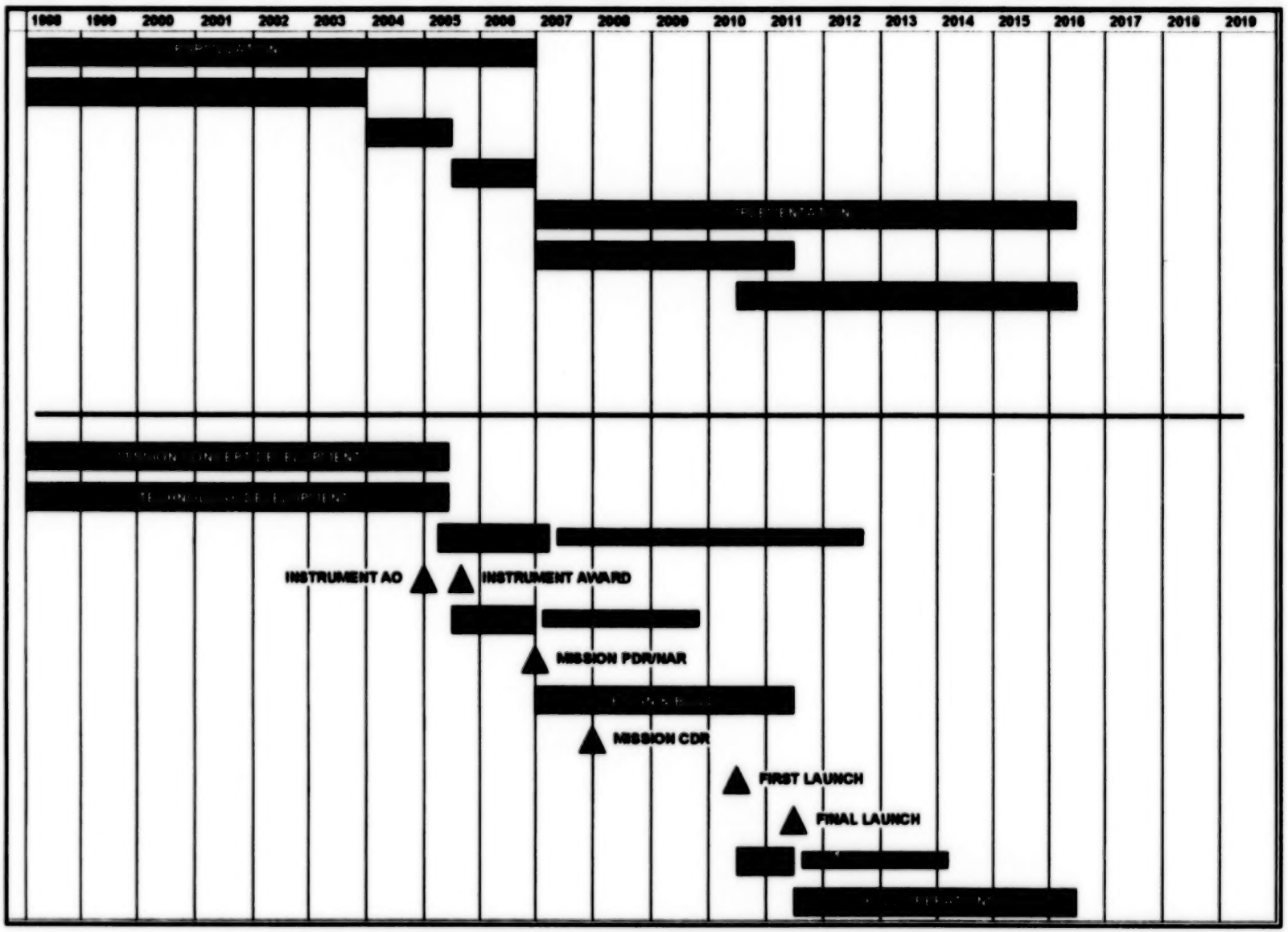
(In Real Year $ Millions)

- **Provides for technology development and mission formulation which, depending on funding profile after FY 2005, is consistent with:**
  - Release of AO for science instruments in FY 2005
  - Approval for new start in FY 2007
  - Readiness for first launch in mid FY 2010
  - All elements of full-up observatory to be operational by mid FY 2011

- **Technology development budget is based on the Constellation-X technology roadmap**
  - Reductions taken for cross enterprise and SBIR funds that have already been received or are planned
  - Assumes SR&T funds supplement X-ray calorimeter, HXT, grating and CCD development prior to FY04
  - Assumes budget from SEU science director's discretionary funds (DDF) earmarked for Constellation-X

Top Level Schedule

Consistent with Re-phased Guidelines



Budget with Augmentation

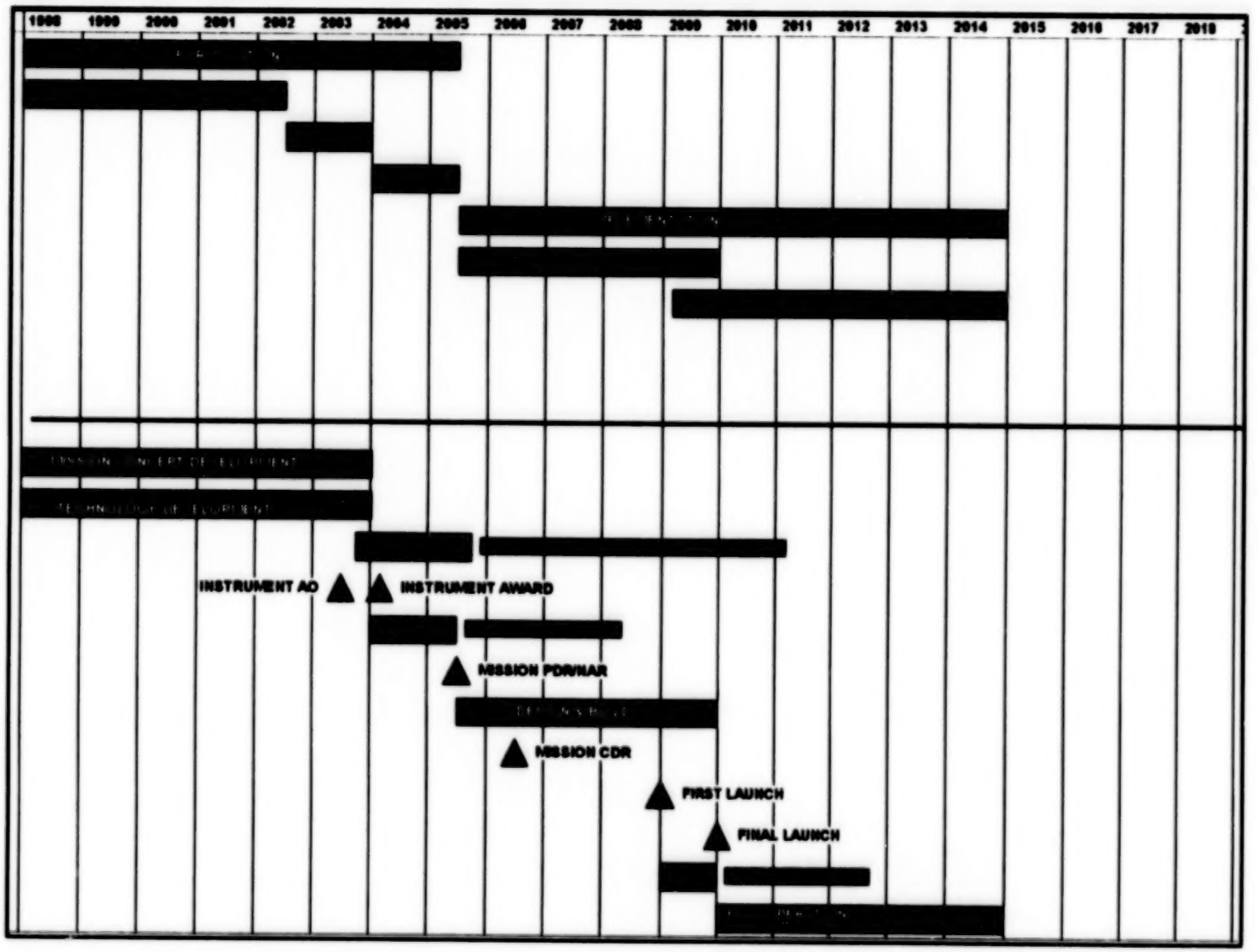
	Prior	FY99	FY00	FY01	FY02	FY03	FY04	FY05	Total
Technology Development	4.2	1.3	1.3	1.3	14.0	18.8			40.8
Mission Formulation	1.0	0.3	0.3	0.3	1.8	5.3			9.0
Definitization							39.0	24.3	63.3
Implementation								54.1	54.1
Total	5.2	1.6	1.6	1.6	15.8	24.0	39.0	78.4	167.2
Guidelines		1.6	1.6	1.6	4.7	5.0	23.0		
Augmentation					11.1	19.0	16.0		

(In Real Year $ Millions)

- **Provides for technology development and mission formulation which, depending on funding profile after FY05, is consistent with:**
  - Release of AO for science instruments in FY 2003
  - Approval for new start in FY 2005
  - Readiness for first launch in late FY 2008
  - All elements of full-up observatory operational by late 2009

- **Technology development budget is based on the Constellation-X technology roadmap**
  - Reductions taken for cross enterprise and SBIR funds that have already been received or are planned
  - Assumes SR&T funds supplement X-ray calorimeter, HXT, grating and CCD development prior to FY02
  - Assumes budget from SEU science director's discretionary funds (DDF) earmarked for Constellation-X

Top Level Schedule for 2005 New Start



Issues

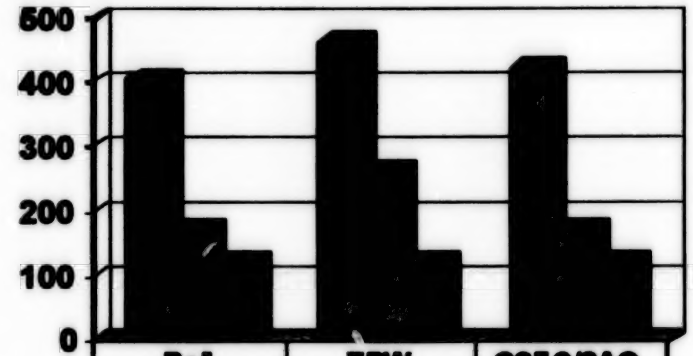
- **Constellation-X is the only mission in the 1997 OSS Strategic Plan not adequately funded to support a new start by 2004**

- **Need to establish earlier launch date to:**
  - Provide for timely transition and continuity in high quality X-ray observations
  - Provide overlap between Constellation-X and Chandra for cross calibration and science synergy (similar to Keck and Hubble Space Telescope)

- **Need to increase current funding guidelines to:**
  - Support technology efforts already selected via peer review in April 1998
  - Maintain momentum and skill base for technology development and mission studies
  - Capitalize on Code S technology investments in Chandra, Astro-E and XMM

Implementation Cost Estimates

- **New cost estimates made by CAN Industry partners and GSFC/SAO:**
  - Independent estimates are consistent

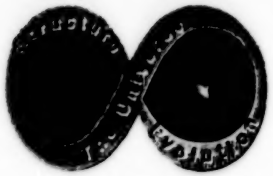


PROPRIETARY

	Ball	TRW	GSFC/SAO
Development	407	464	423
Launch Vehicle	176	264	176
Operations	124	124	124

FY98 Fixed $ Millions

- **Cost estimation assumptions and methodology:**
  - Costs are for implementation phase; do not include technology development or mission formulation
  - Ball: 2 satellite configuration estimated by combination of grass roots and parametric models
  - TRW: 3 satellite configuration estimated by parametric models at the component level
  - GSFC/SAO: 4 satellite configuration estimated by grass roots method
  - Instrument costs (part of Development) estimated by GSFC using parametric models
  - Launch vehicle estimates based on published EELV data for Atlas V/5
  - Contingency is not included

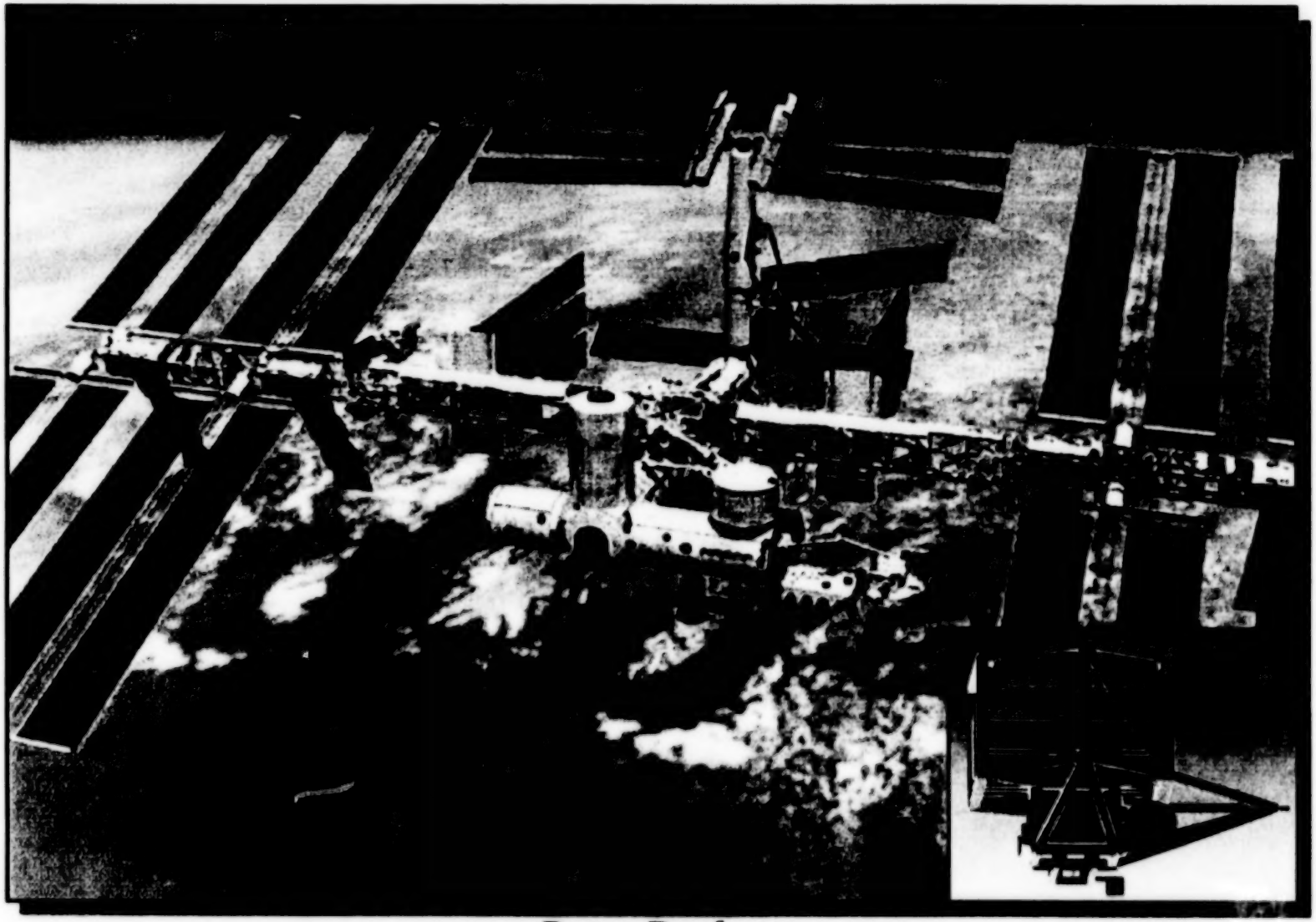


The Outlook for Constellation-X

- **One-year outlook (Spring 2000)**
  - Complete 0.5 m optic at required weight (1/6 mass normalized to XMM)
  - Continue to improve X-ray calorimeter resolution
  - Continue development of mission configuration; define error and alignment budgets

- **Five-year outlook (Spring 2004)**
  - With current in-guide budget:
    - Conducting Phase A mission studies with two industry partners
    - Technology development in progress
    - Drafting instrument AO in preparation for release
    - About to begin development of SXT production facility
  - With requested augmentation:
    - Technology development is complete
    - Instrument AO has been released and the instruments have been selected
    - Mission Prime contractor has been selected
    - Preliminary design is well underway
    - Mission PDR and NAR will occur within the next year

Advanced Cosmic-ray Composition Experiment for Space Station (ACCESS)



Betsy Park
Goddard Space Flight Center
http://lheawww.gsfc.nasa.gov/ACCESS

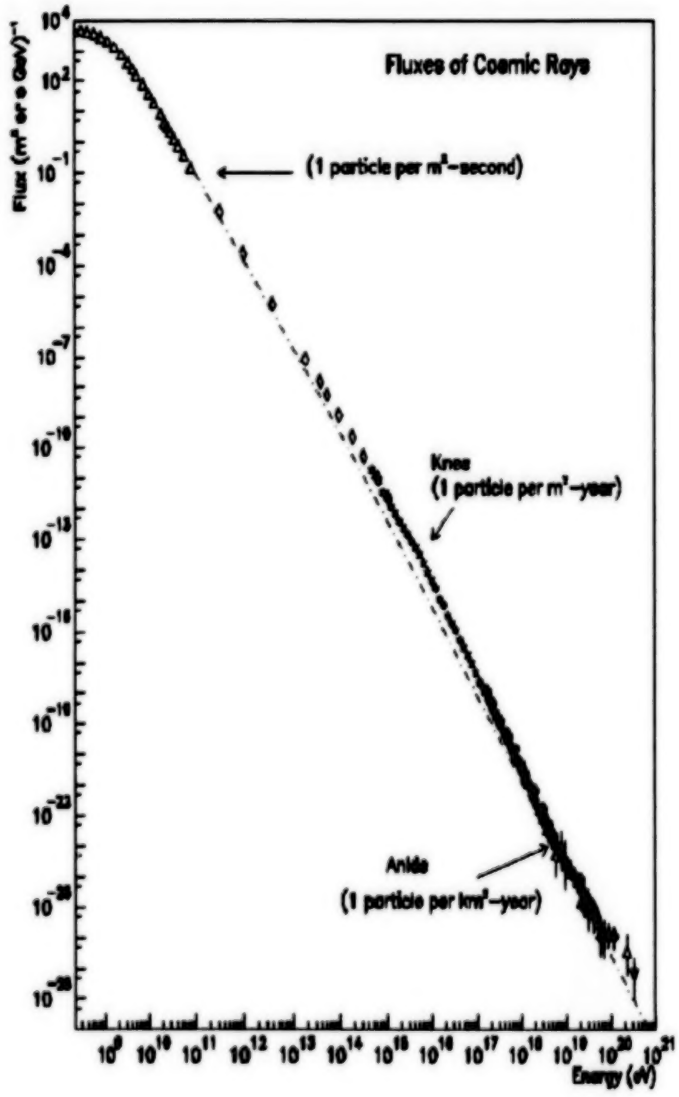
Science Overview

How Do Cosmic Rays Gain Their Enormous Energies?

- **How and where are cosmic rays injected into the "accelerator" of cosmic radiation? What is the source of material injected?**
  - Signature provided by measurements of ultra-heavy abundances
- **How are cosmic rays accelerated?**
  - Measure spectral changes of element spectra taken at maximum energies expected from supernova shock acceleration
- **How do cosmic rays escape from the Galaxy?**
  - Measure abundance of "spallation" nuclei

Science Goal

- **Measure ~ 30 times more P, He events than Japanese American Cooperative Emulsion Experiment (JACEE) balloon flights (1979 - 1995)**
- **Measure ~ 10 times more Z > 4 events than combined total of all previous data**
  - High Energy Astrophysics Observatory (HEAO C3)(1979) flight and ARIEL 6 Trans Atlantic balloon flight (1979)



Science Requirements

Science Goals

- **Cosmic ray origins**
  - How is material selected for injection into the cosmic ray accelerator?
- **Cosmic ray accelerator**
  - How do cosmic rays gain their enormous energies?
- **What is the energy dependence of a cosmic ray's lifetime in the galaxy?**

Measurement Capabilities

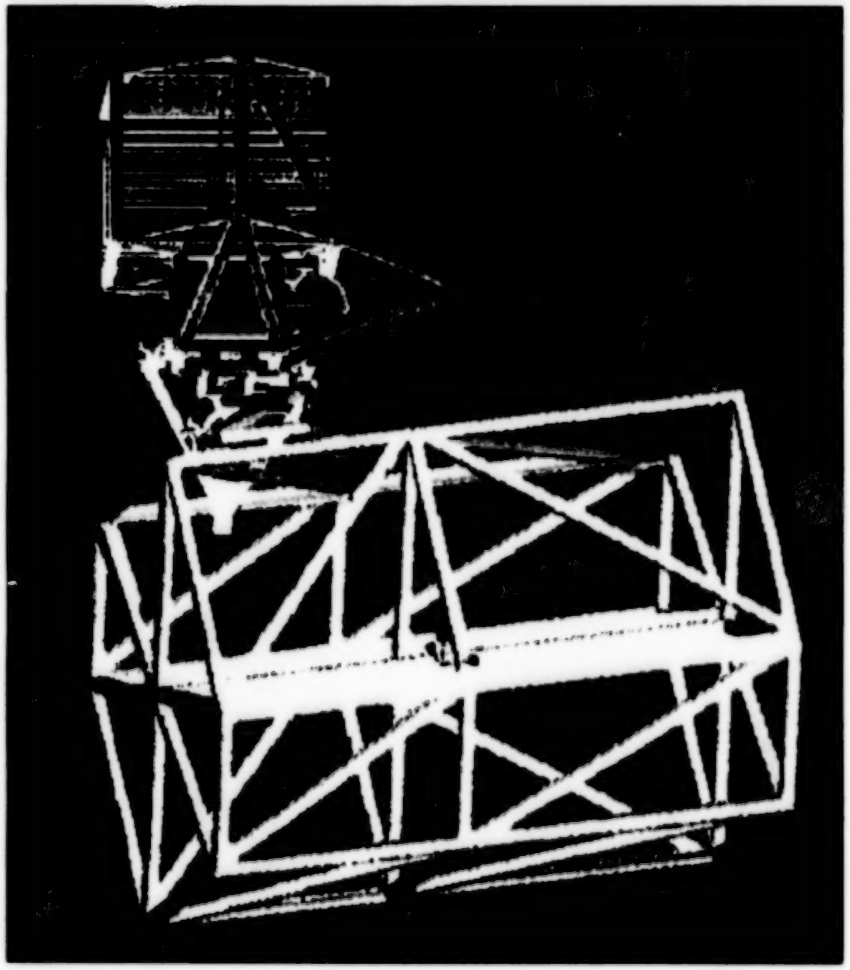
- **Energy spectra range: $10^{12} \leq E \leq 10^{15}$**
- **Charge resolution:**
  - Identify Z = 1 to 26 for $10^{12} \leq E \leq 10^{15}$ eV
  - Identify Z = 26 to 83 for 0.5 to ~6 GeV/n
- **Energy resolution:**
  - P, He < 40% @ 10^{12} to 10^{15} eV
    Be - Fe < 20% @ 10^{12} to 10^{15} eV
- **Exposure:**
  - 300 m^2-sr-days for H, He
  - 8000 m^2-sr-days for $Z \geq 4$

Engineering Implications

- **Lifetime**
  - 1000 days of full operation
- **Large Detectors**
  - Area > 4 m^2
    Calorimeter > 0.7 m^2
  - Calorimeter depth $\geq$ 28 radiation lengths
- **Total mass 5225 kg**

International Space Station Attached Payload

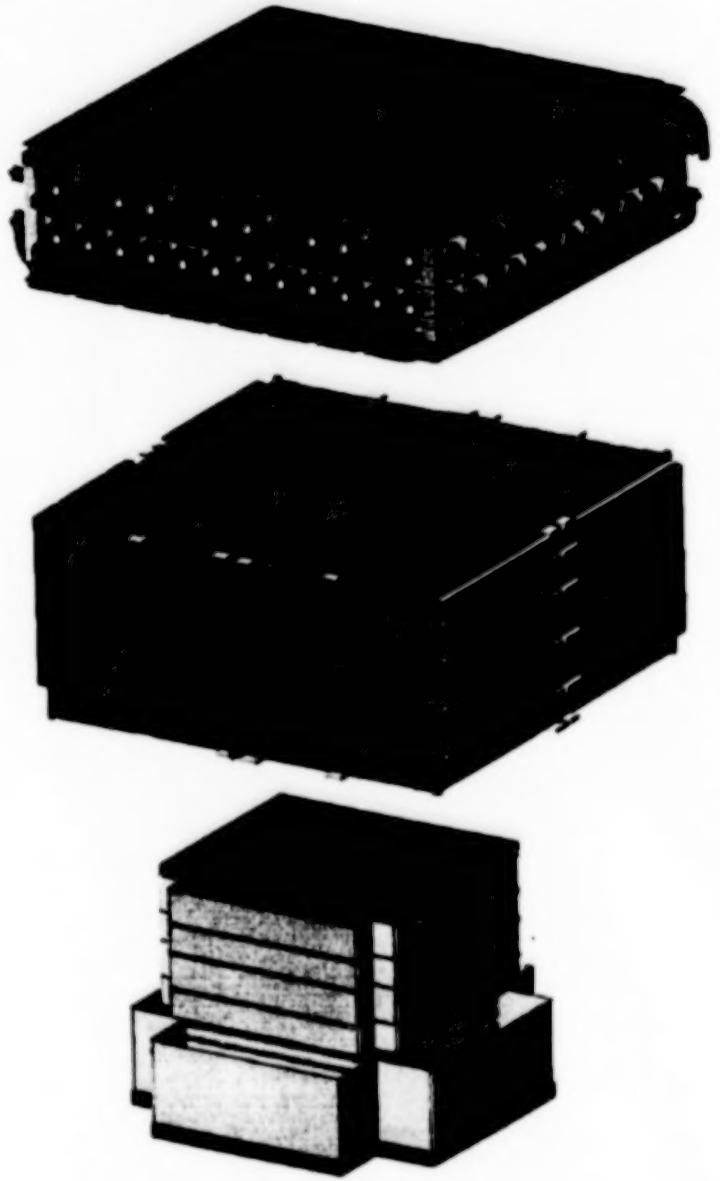
ISS provides an observing platform for ACCESS, a large payload with tolerant pointing requirements



- **Launch on STS, 2006 - 2007 timeframe**
  - Replace Alpha Magnetic Spectrometer (AMS) on Starboard full zenith attach site
- **4 years on-orbit to achieve 1000 days operating time**
- **Mass - 5,225 kg**
- **Volume - 2.5m X 2.5m X 2.8m**
- **Power - 850W**
  - Projected 80% duty cycle
- **Telemetry - 300 kbps (avg)**

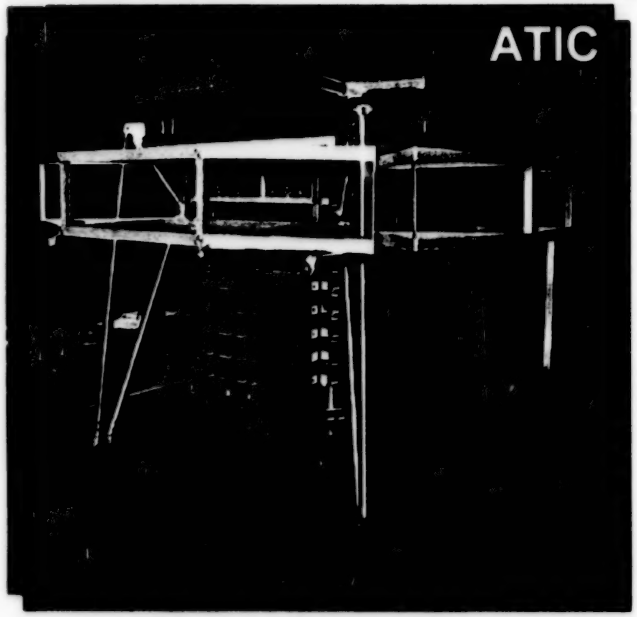
Mission Concept

- **Baseline Instruments**
  - **Charge Identification Module (ZIM)**
    - › Element identifier via Silicon detectors
    - › Measures particle velocity via Cherenkov detectors
  - **Transition Radiation Detector (TRD)**
    - › Measures relativistic velocity via transition radiation
    - › Transition X-rays measured with Xe gas tubes
  - **Hadron Calorimeter**
    - › Measures energy deposition via inert Carbon target with BGO crystal scintillators
- **Payload Interface Bus (PIB)**
  - Provides complete interface between instruments and the STS/ISS
  - Structure may also serve as STS carrier



Technology Development

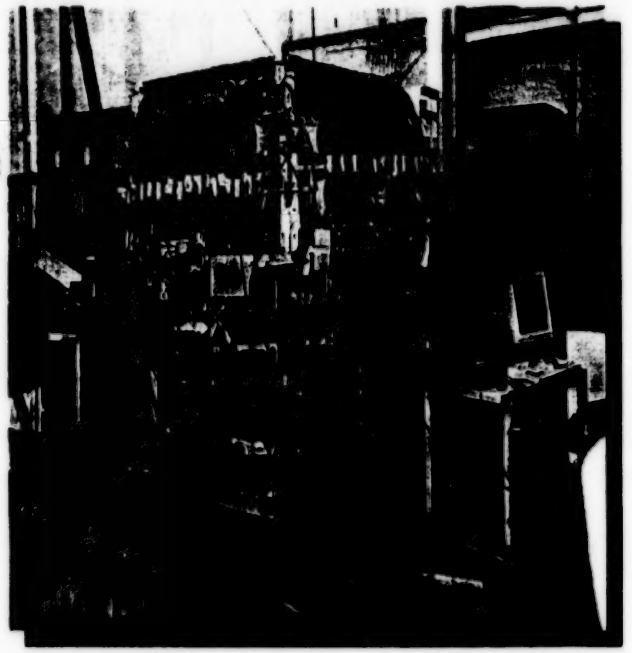
Technology development funded by balloon research grants



Advanced Thin Ionization Calorimeter precursor for Hadron Calorimeter

Transition Radiation Array for Cosmic Energetic Radiation precursor for TRD

Trans Ion Galactic Element Recorder precursor for ZIM on Ultra Long Duration Balloon (ULDB) Flight



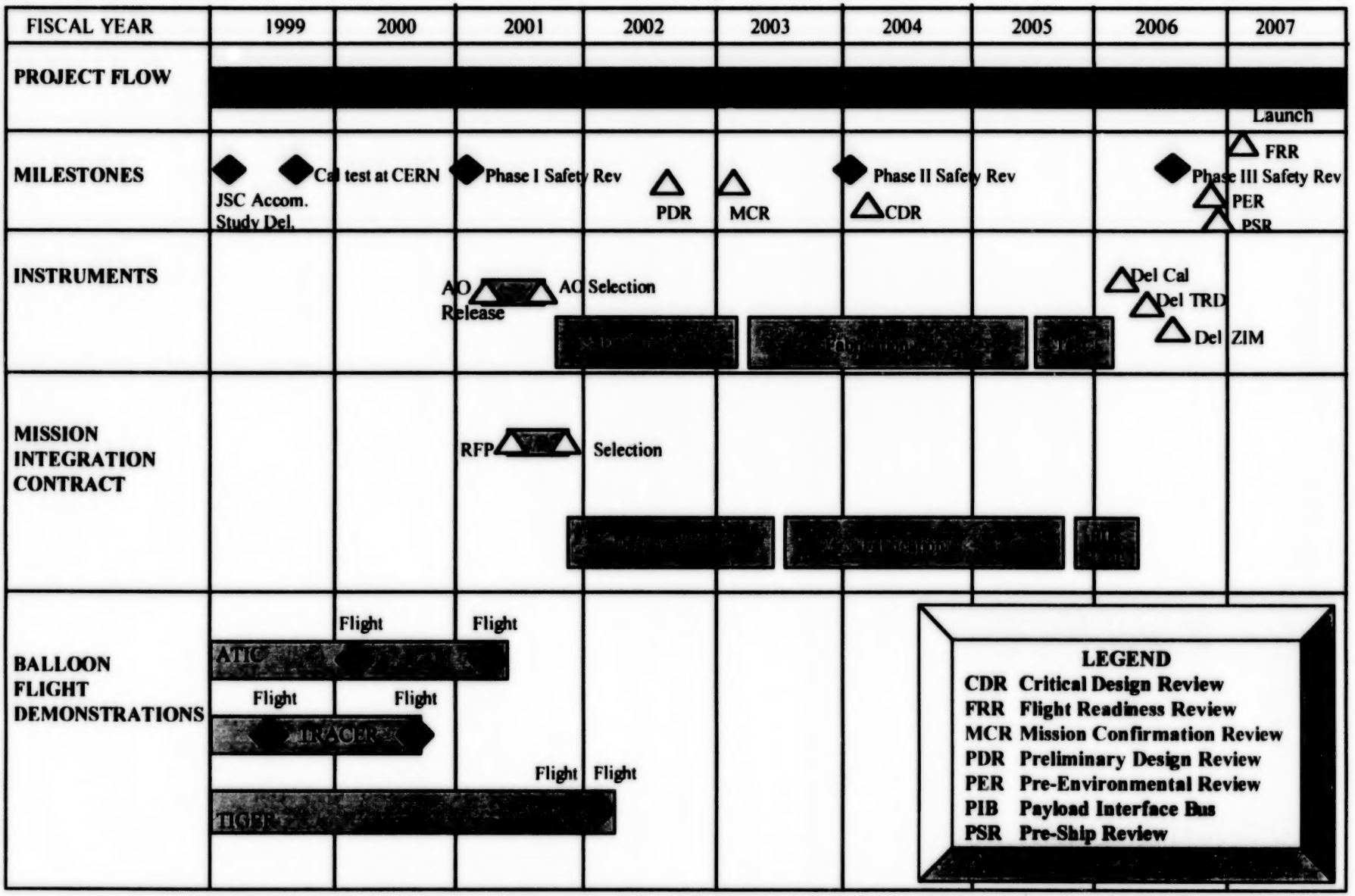
ASIC Development for particle charge identification

- Analog, large dynamic range

Gas tube detectors

- Individual tubes withstand external vacuum, no pressure vessel

Top Level Schedule



Progress

- **Formulated baseline design concept**
  - Demonstrated mission feasibility
  - Independent Review at GSFC in Mission Systems Review, 1/99
- **Completed schedule and grassroots cost estimate**
- **LSU/JSC Accommodation Study of 1997 concept completed**
- **Established interfaces with ISS Payloads Office / attached payloads forums**
- **Calorimeter**
  - Calorimeter Simulation Team has studied signal response and energy resolution of baseline and alternate calorimeter designs
  - Arrangements made for calorimeter testing at CERN
  - Calorimeter Workshop held at Texas Tech University, 10/98
- **TRACER in final preparation for Fairbanks balloon flight**
- **Outreach**
  - Produced ACCESS brochure and web site (http://lheawww.gsfc.nasa.gov/ACCESS/)
  - ACCESS technical session held at STAIF-99 (Space Technology and Applications International Forum)
  - Preparing information for June 1999 AAS booth

Budget

NASA Cost (Real Year $M)

ACCESS Mission	Prior	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
SR&T Program Sup	2.0	1.2	0.7	0.7											4.6
Formulation					4.6										4.6
Implementation						20.0	26.3	22.6	19.2	9.3					97.4
MO & DA										1.4	2.8	2.9	3.0	2.0	12.1
ACCESS Total	2.0	1.2	0.7	0.7	4.6	20.0	26.3	22.6	19.2	10.7	2.8	2.9	3.0	2.0	118.7

Assumptions

- POP submission for FY01 budget
- Total Lifecycle cost capped at $100M in FY99 dollars
- New start in FY03
- Programmatic reserves are included at 25%
- Full cost accounting not included
- Formulation enabling activities funded by SR&T Program, balloon flights not included
- Mission integration contract to build Payload Interface Bus and perform mission integration and test
- STS integration and launch costs provided by Code M
- ISS Program provides: ISS simulators and portions of ground systems, operations, data processing, and data archive

The Outlook for ACCESS

- **1-Year Outlook (Spring 2000)**
  - Successfully included in OSS Strategic Plan
  - Baseline and alternate Calorimeters tested in beam at CERN
  - NRA instrument studies complete
  - ATIC and TRACER first balloon flights complete
  - Plan and concept design to meet cost cap complete
  - Complete second concept design for alternate instruments
  - Instrument AO and Mission integration RFP initiated draft
- **5-Year Outlook (Spring 2004)**
  - AO competition and selection complete
  - Instruments completing fabrication
  - Mission Integrator under contract
  - Payload Interface Bus in fabrication
  - Mission CDR and Phase II Safety Review complete
  - ISS truss assembly complete

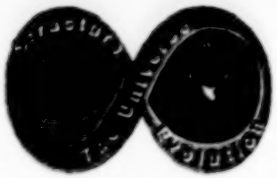
Laser Interferometer Space Antenna (LISA)

Exploring the Gravitational-Wave Universe

Bill Folkner

Jet Propulsion Laboratory

http://lisa.jpl.nasa.gov



Questions

- **What are the pre-cursors to Type Ia supernovae?**
  - When and where will a type Ia supernovae next occur in our galaxy?
- **How did the massive black holes at the centers of galaxies form?**
- **What is the structure of space and time near massive black holes?**
- **What happened in the Universe before light could propagate?**
  - What is the 'dark side' of the Universe?

The Gravitational-Wave Sky

The next chart shows an image of the sky as viewed by gravitational waves.

The Milky Way galaxy forms the band in the middle of the image. LISA will see thousands of binary star systems in our galaxy. Most of these will be White Dwarf binaries with orbital periods of a few hours. Some will contain neutron stars or black holes. LISA will be able to determine the position (direction and distance) to each binary, as well as the periods of the orbits and the masses of the stars.

Type Ia supernovae may occur when white dwarf binaries ,with total mass 1.4 times the mass of the sun, lose enough energy to gravitational waves for the stars to collide. LISA will determine the directions to, and time of collision, for the next 500 type Ia supernovae in our galaxy.

Outside our galaxy, binary stars will be too weak to be seen. Instead, there LISA will see gravitational waves associated with the massive black holes in the centers of other galaxies (millions of times the mass of our sun).

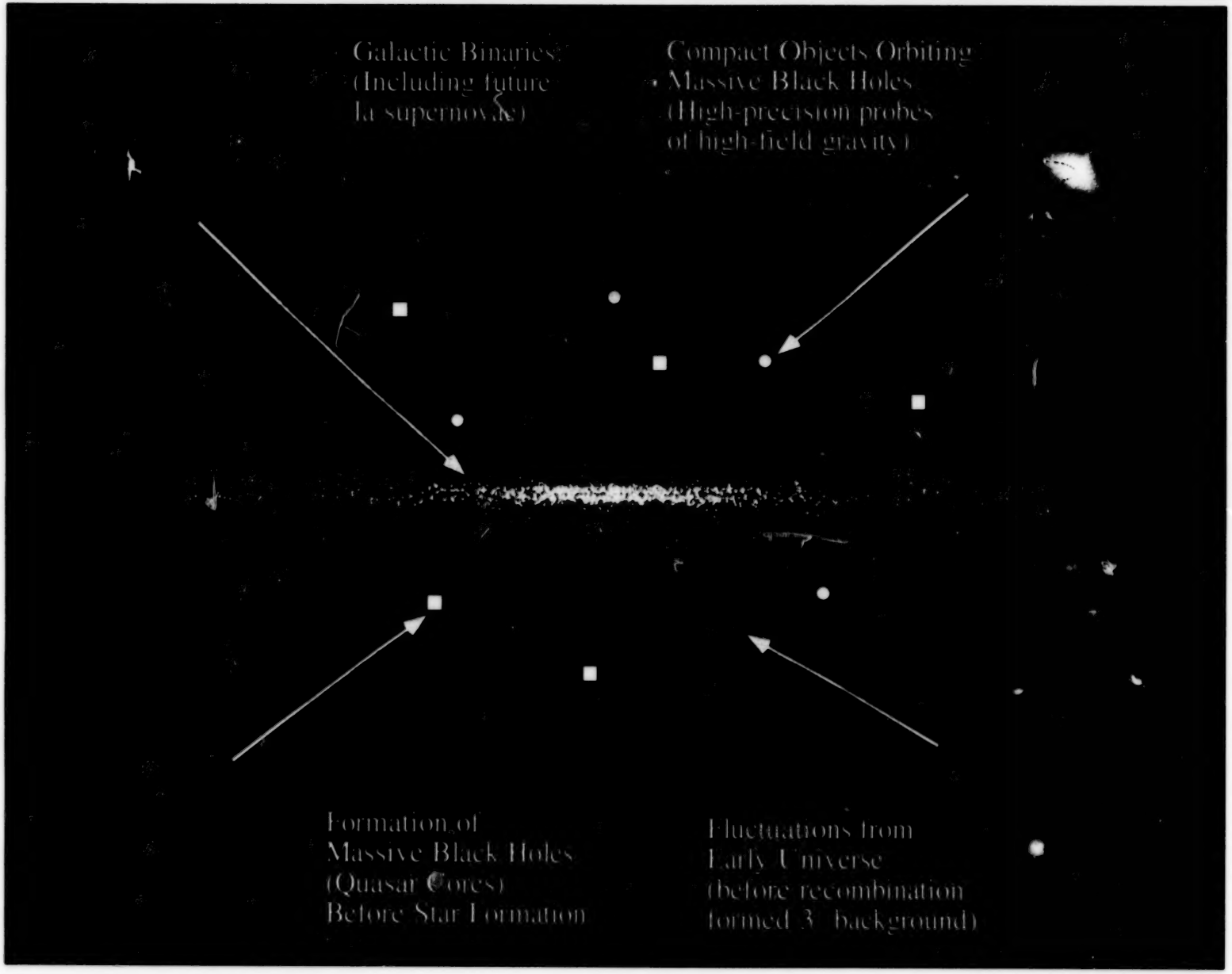
Massive black holes may have formed before most stars. They may have originated from the coalescence of smaller black holes. LISA will investigate this and other formation mechanisms for massive black holes.

When galaxies collide, the massive black holes at their centers will interact, producing prodigious amounts of gravitational radiation, the most energetic events in the Universe. LISA will see these anywhere they occur in the Universe, probably several per year.

When normal black holes (a few times the mass of our sun) fall into massive black holes in the centers of galaxies, they will undergo bizarre orbit changes and emit gravitational waves. LISA will see these waves, which will provide a high precision test of General Relativity in the region near massive black holes.

The early Universe was so hot that all particles were ionized, making it impossible for light to travel until the universe cooled enough for atoms to form. LISA may see gravitational waves from the early Universe as a background similar to the 3 degree radiation background imaged by COBE but much earlier in time. This will reveal new information on the origin of structure in the Universe and the physical processes of extreme states of matter.

The Gravitational-Wave Sky



Gravitational Waves Through Time

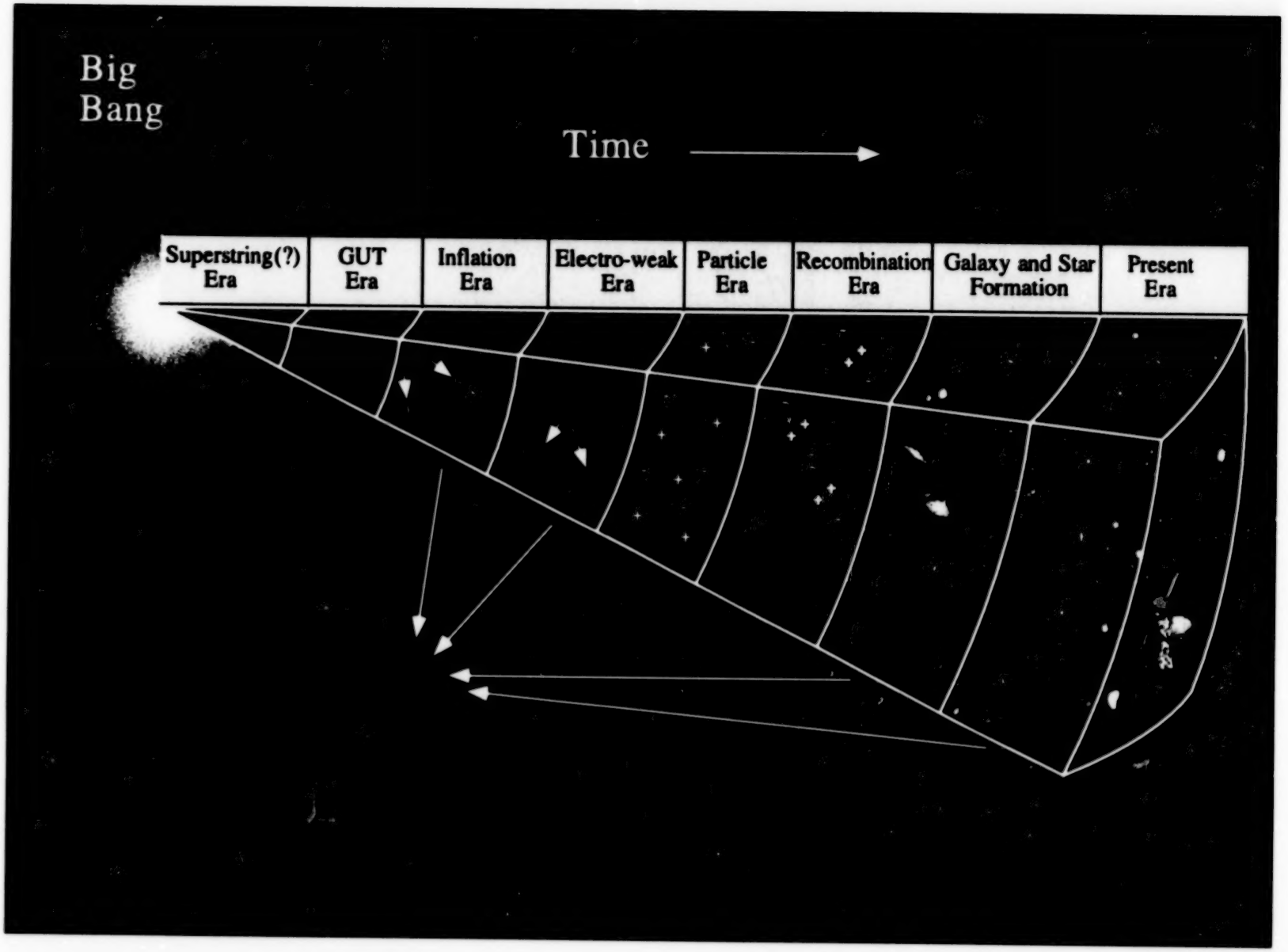
The next figure highlights some events in the history of the Universe as it evolved from the Big Bang.

The early Universe was so hot that atoms could not form, and the strong and weak nuclear forces were not distinguished from electromagnetism (the so-called Grand-Unified Theory era). As the Universe cooled, the forces separated. The Universe also probably underwent a stage of exponential expansion, called Inflation, that made local bubbles of uniform fairly uniform density, like the visible part of the Universe revealed by telescopes.

In the hot, early Universe, light could not propagate freely. Not until the universe cooled enough that protons and electrons formed atoms (called Recombination) could light travel and show images of local structure. Telescopes in the electromagnetic spectrum (radio, infra-red, visible, X-ray, gamma-ray, etc.) can never see back into the hot, early Universe.

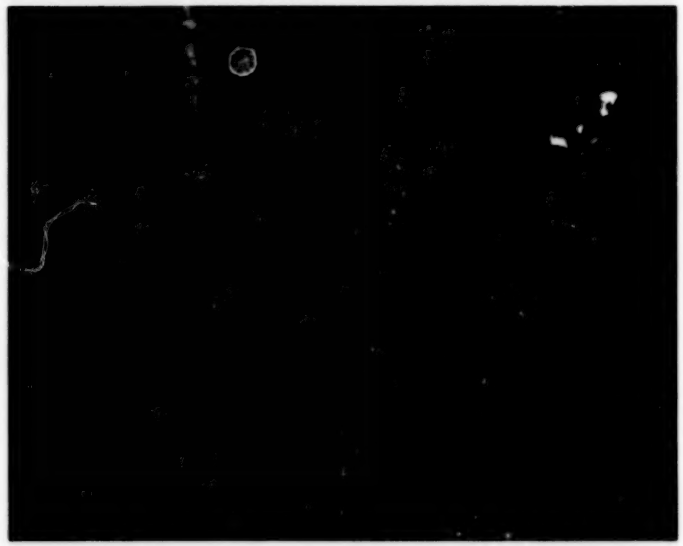
Gravitational do not interact electromagnetically and thus could propagate freely in the early universe. LISA may see gravitational waves from the early Universe as a background similar to the 3 degree radiation background imaged by COBE but much earlier in time. This will reveal new information on the origin of structure in the Universe and the physical processes of extreme states of matter.

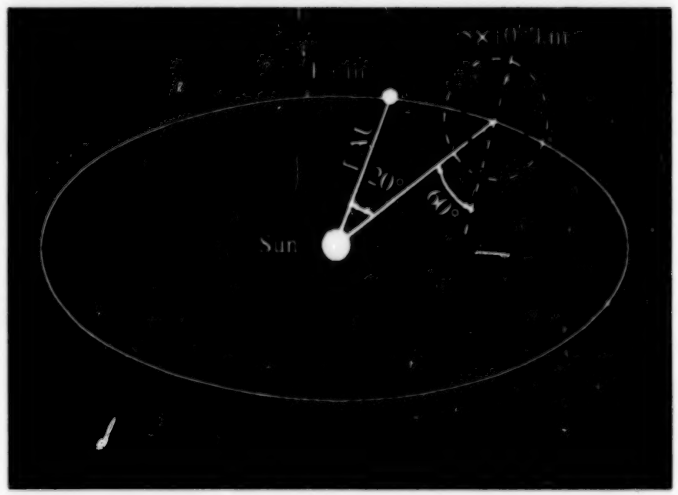
Gravitational Waves Through Time



Mission Concept

- **Mission:**
  - 3 spacecraft separated by 5×10^6 km
  - A 'Michelson Interferometer' is formed to measure changes in separation caused by gravitational waves.
- **Approach:**
  - Each spacecraft includes 2 freely falling test masses
  - Gravitational waves cause distance changes between test masses
  - Distance changes of 20 pm measured
  - Test masses must be free of non-gravitational forces
    - › 'Drag-free' operation
    - › Micronewton thrusters
- **International Teaming**
  - Identical mission concept is being studied by ESA
  - ESA baseline is to negotiate a 50/50 sharing between ESA and NASA





The Gravitational-Wave Spectrum

The next figure shows the amplitude and frequency ranges of sensitivity to gravitational waves of LISA and LIGO (a ground-based observatory).

Just as light is characterized by its wavelength, or frequency, gravitational waves have different wavelengths and frequencies. (Wavelength times frequency gives the speed of wave propagation, which is the same for light and gravitational waves).

The most sensitive frequencies for LISA and LIGO differ by six orders of magnitude. In the analogous region of the electromagnetic spectrum, this would be like comparing gamma rays to visible light. Like gamma-ray telescopes, LIGO will see brief events of great energy, and interest, analogous to gamma-ray bursts. Like the Hubble Space Telescope, LISA will see a large number of continuously bright signals from compact stars and from other galaxies.

Ground-based observatories cannot see the low-frequency gravitational waves that are the focus of LISA. On the ground, the changing gravitational environment, due to earthquakes, tides, and human machinery, cause perturbations on test masses that cannot be distinguished from gravitational waves. Only a space observatory like LISA can see the low-frequency gravitational-wave Universe.

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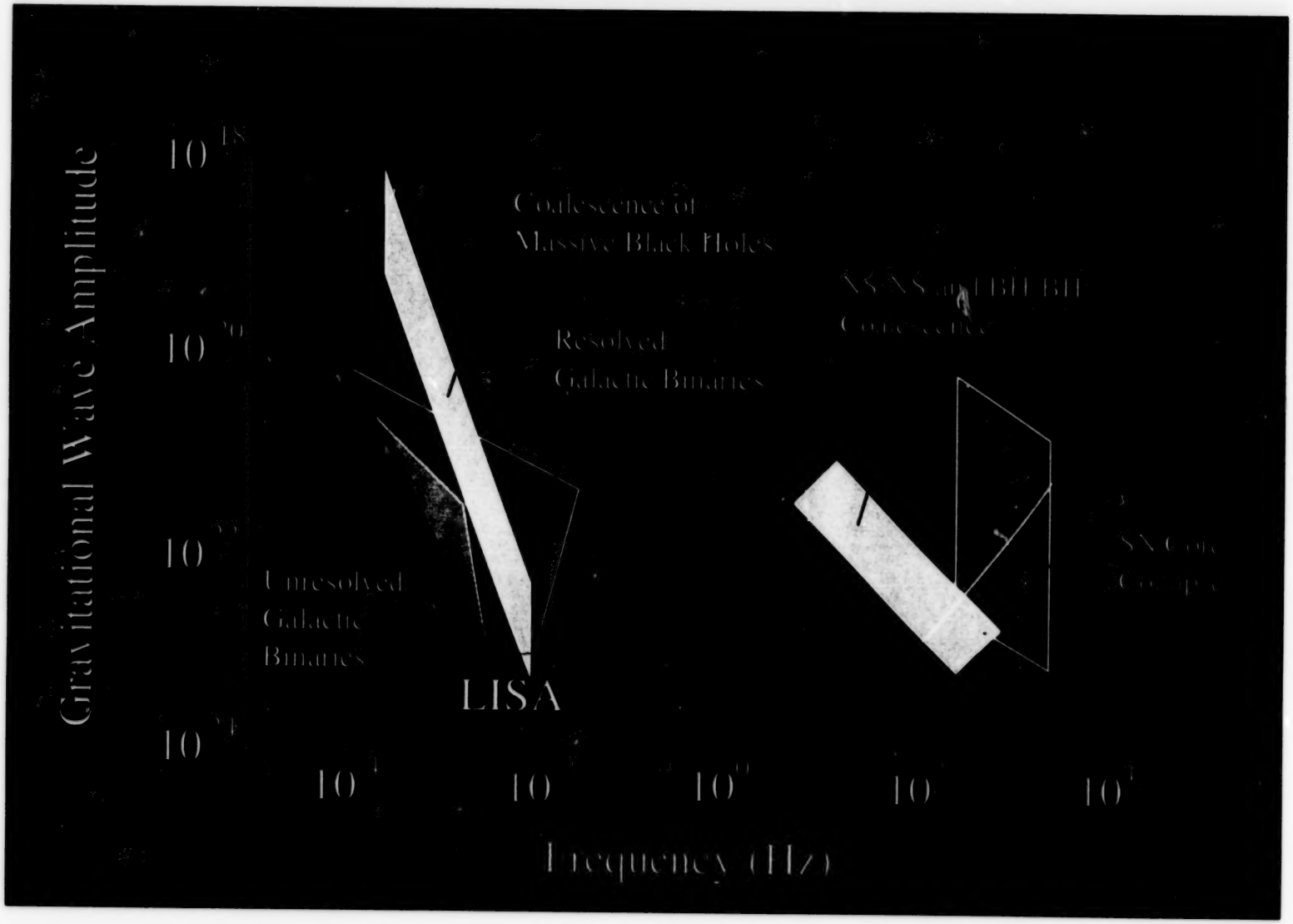
The Gravitational-Wave Spectrum



Technology Drivers

The next figure shows the role of the key technologies needed for the LISA mission.

LISA forms a giant Michelson interferometer in space. The interferometer measures changes in distance between one pair of spacecraft compared with another pair. Gravitational waves cause one arm of the interferometer to lengthen and the other arm to shorten. Three spacecraft forming two-arms are required to cancel the noise of the signal source used to make the measurements (lasers in the case of LISA).

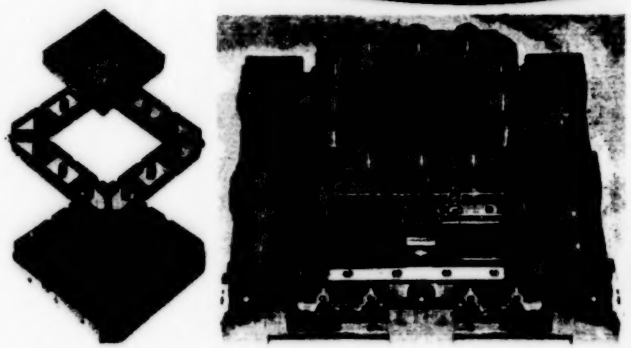
The gravitational wave signals cause very small changes in distance, of order 10 picometers, or one-tenth the size of an atom. The laser interferometers use the very short laser wavelength to measure changes in distance between test masses in different spacecraft. (The average motion of the test mass over the large number of atoms they contain allow measurement precision much finer than the size of a single atom).

The laser interferometry needed for LISA is similar to the interferometry used in ground-based observatories like LIGO. The main differences are that LISA operates at much lower frequencies, and thus needs stability over hours instead of milliseconds, and LISA needs 7 orders of magnitude (ten million times) LESS precision than LIGO. The laser interferometry for LISA thus needs development for long-term stability, but is not challenging in terms of precision.

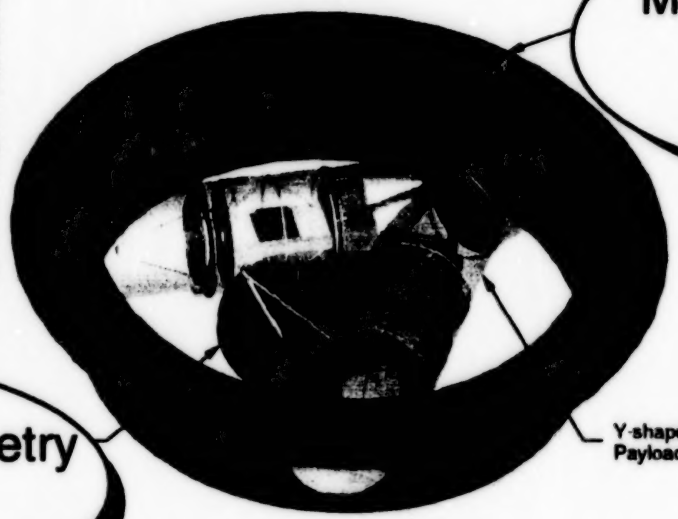
The key technology need for LISA is the need for test masses that are free of motion from forces other than gravitational waves at an acceleration of 10^{-16} times the Earth's gravity, to give noise-like motions less than 10 picometers. Achieving this low level of noise requires that the test masses be shielded from external influences, such as sunlight, and requires that the spacecraft be kept precisely centered on the test masses. The precision spacecraft control requires new types of thrusters for the continuous fine control forces needed.

Technology Drivers

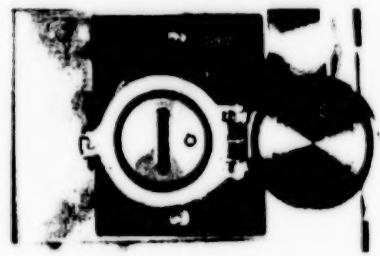
Inertial sensors
Noise < 10^{-15} g

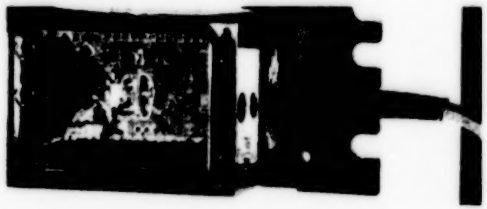


Micronewton thrusters
Range 1-100 μN
Noise <1 μN



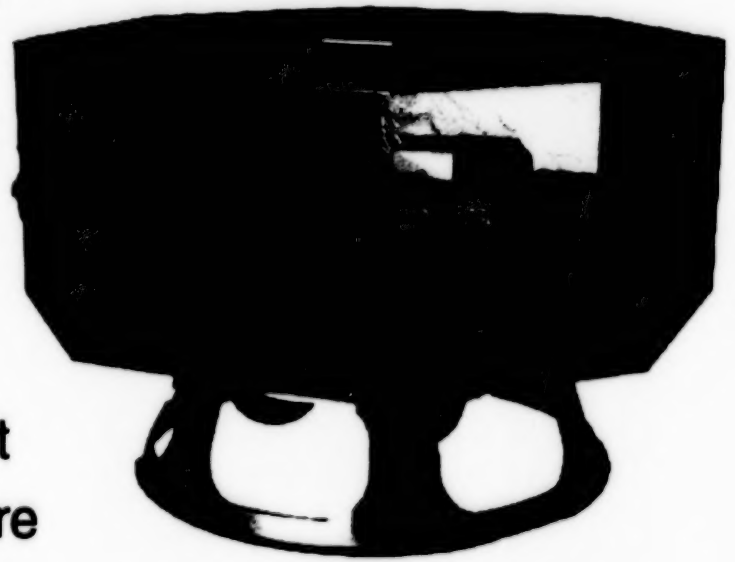
Picometer interferometry
1 W laser
Accuracy < 20 pm





Technology Flight Demonstration

- Of the key LISA technologies, only one, the low-noise inertial sensors, requires a space environment for testing
- The LISA Technology peer review panel recommends a flight demonstration
- One of three competing mission concepts for the New Millennium ST5 opportunity could validate the LISA inertial sensors
  - Selection July 1999
  - Launch 2002/2003
  - $28M cost cap (all inclusive)
  - Two inertial sensors on one spacecraft
- Other flight demonstration opportunities are being studied in Europe



Cost and Schedule

Phase	Cost ($M) (FY 99)	Comments
Technology Development	35	Flight demo not included
Mission Definition	40	Phase A/B
Mission Construction	300	Phase C/D; 20% reserves
Launch Vehicle	60	
Operations	30	Phase E; for 4 years
Total	465	

Proposed cost sharing; 50% by NASA
50% by ESA and member space agencies

Working toward inclusion in the 2000 OSS Strategic Plan with a potential new start date in the 2007 time frame.

Progress

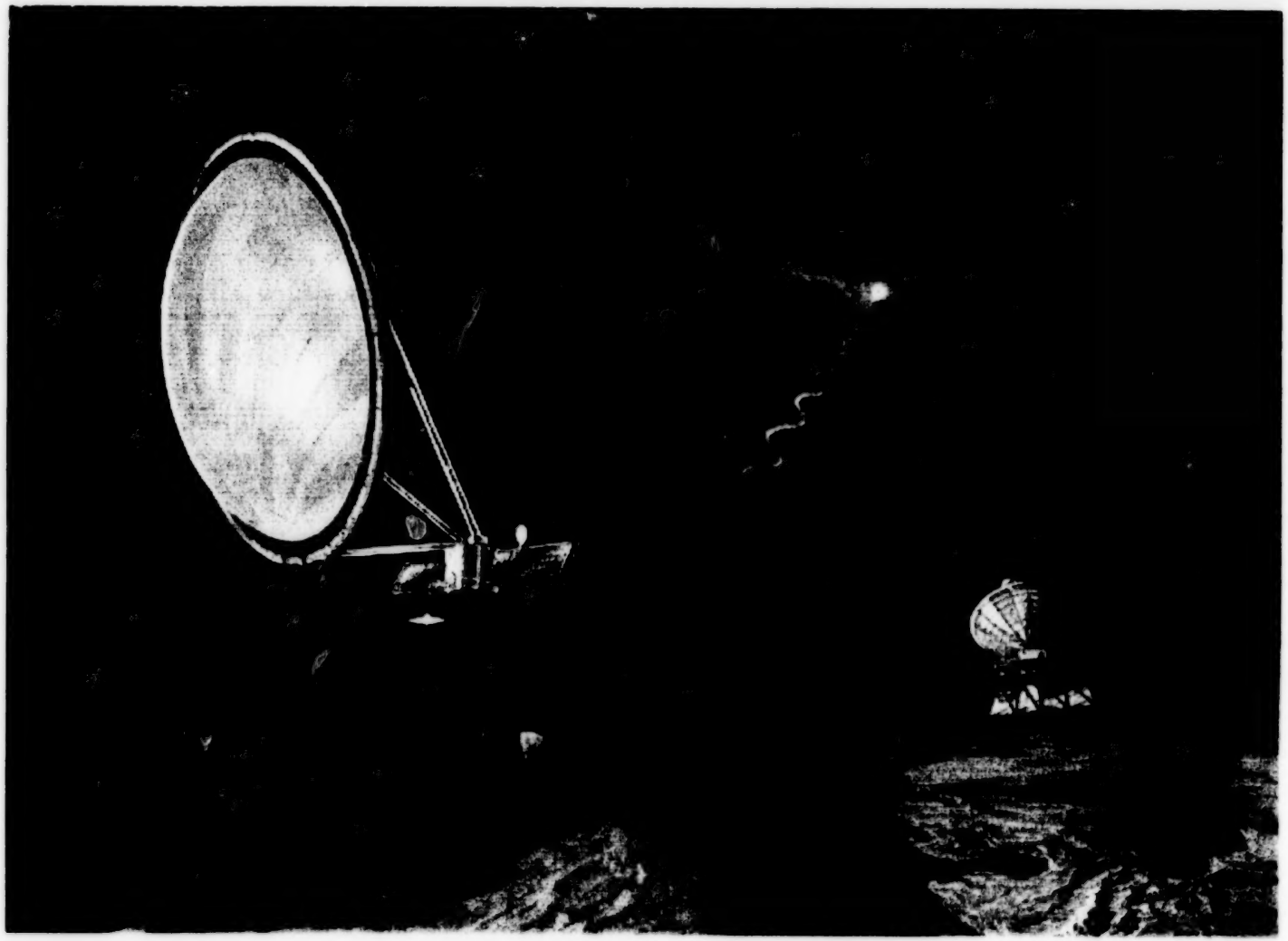
- Active international science team in operation
- New exciting source predictions at 2nd International LISA Symposium
- Detailed mission design developed between US and Europe
- Pre-Phase A report produced, giving thorough mission description
- Mission cost re-assessed August 1998, reduced by 15%
- Technology Plan developed
- Technology plan peer-reviewed February 1999
- Presentation to SEUS made February 1999
- Presentation to NRC Decennial Survey panel made March 1999
- Laser interferometry development initiated in Europe
- Flight test of micro-thrusters planned for test on STS in FY 2000
- ESA industrial Phase A study begun February 1999

Outlook

- LISA will observe low-frequency gravitational waves, producing science results of 'Nobel-prize' quality
- LISA is consistent with the NASA Grand Challenge to view the 'dark side' of the early Universe when light could not propagate
- LISA will pinpoint the locations and times of the next ~500 type Ia supernovae in the Milky Way, our galaxy's "4th of July fireworks"
- The needed technology is identified and can be developed in ~5 year time frame
- With international partnership, LISA can provide Great Observatory Science at Discovery mission price to NASA

- LISA POP guideline of ~$100k/year for foreseeable future will limit progress

Advanced Radio Interferometry between Space and Earth (ARISE)



Artur B. Chmielewski
Jet Propulsion Laboratory
http://arise.jpl.nasa.gov

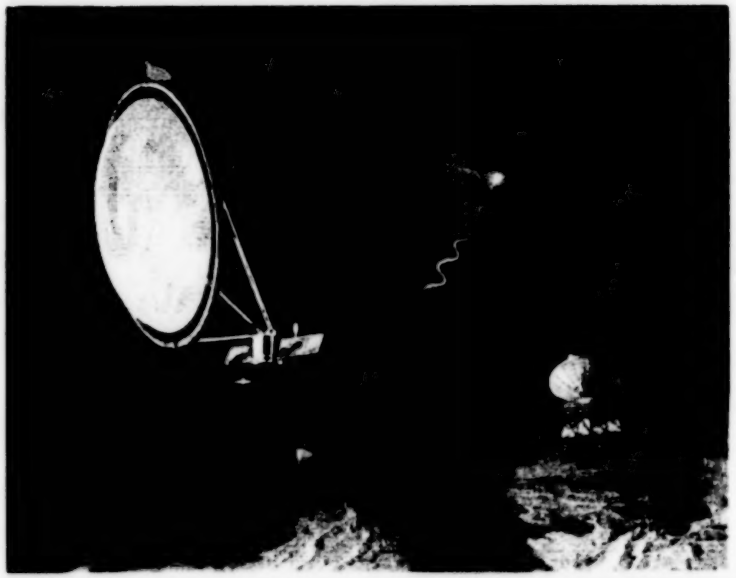
ARISE Team

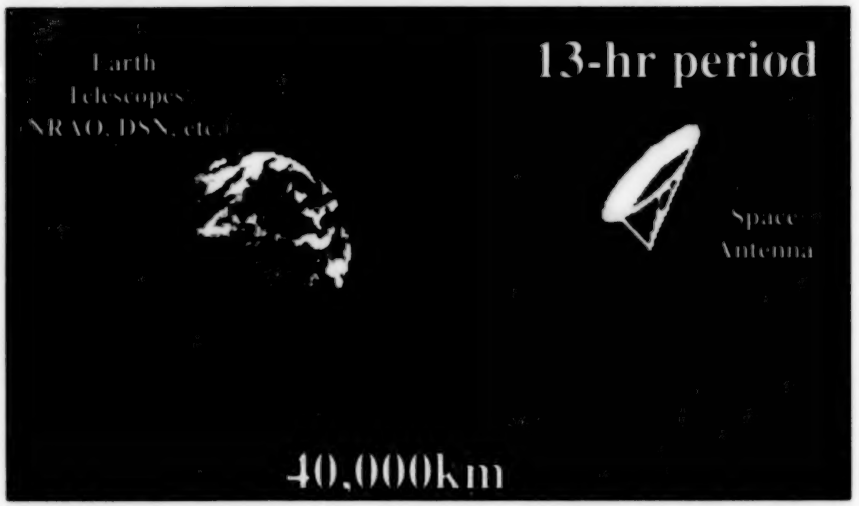
Project Scientist, James Ulvestad, NRAO
JPL - Spacecraft Team
L'Garde - Inflatable Antenna
Harris Corp. - Mechanical Antenna
ILC Dover - Structures
UCLA - antenna performance
COI Inc. - adaptive subreflector
U. of Arkansas - inflation system

Science Advisory Group

A. Marscher, Chair	Boston U.	R. Linfield	Caltech/IPAC
P. Diamond	England	C. Moore	Netherlands
M. Elitzur	U. of Kentucky	D. Murphy	JPL
D. Gabuzda	Netherlands	R. Mutel	U. of Iowa
M. Garrett	Netherlands	S. Neff	GSFC
L. Greenhill	CfA	R. Preston	JPL
L. Gurvits	Netherlands	J. Romney	NRAO
J. Hewitt	MIT	R. Taylor	Canada
H. Hirabayashi	Japan	E. Valtaoja	Finland
A. Konigl	U. of Chicago	A. Wehrle	Caltech/IPAC
J. Krolik	Johns Hopkins	A. Zensus	Germany

ARISE Mission Description





VLBI Observing Parameters

- Image compact radio sources with resolutions of 10-100 microarcseconds with orbiting 25 m inflatable radio telescope working in conjunction with ground telescope arrays
- Observing bands: 8, 22, 43, 86 GHz
- Data Rate: 1-8 Gbit/s
- System Noise Temperatures: 10-40 K

Programmatics

- Mission life 3 yr.
- Launch vehicle Delta
- Potential joint international project

ARISE Key Science Goals

Image and understand the environments of supermassive black holes

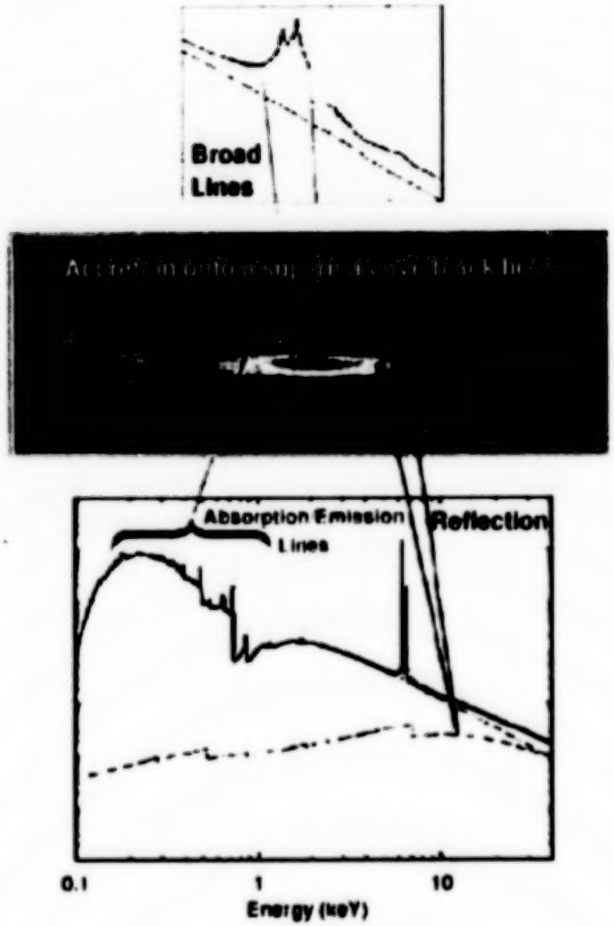
Cosmology
- Gravitational Lens Studies
- High Redshift Radio Sources

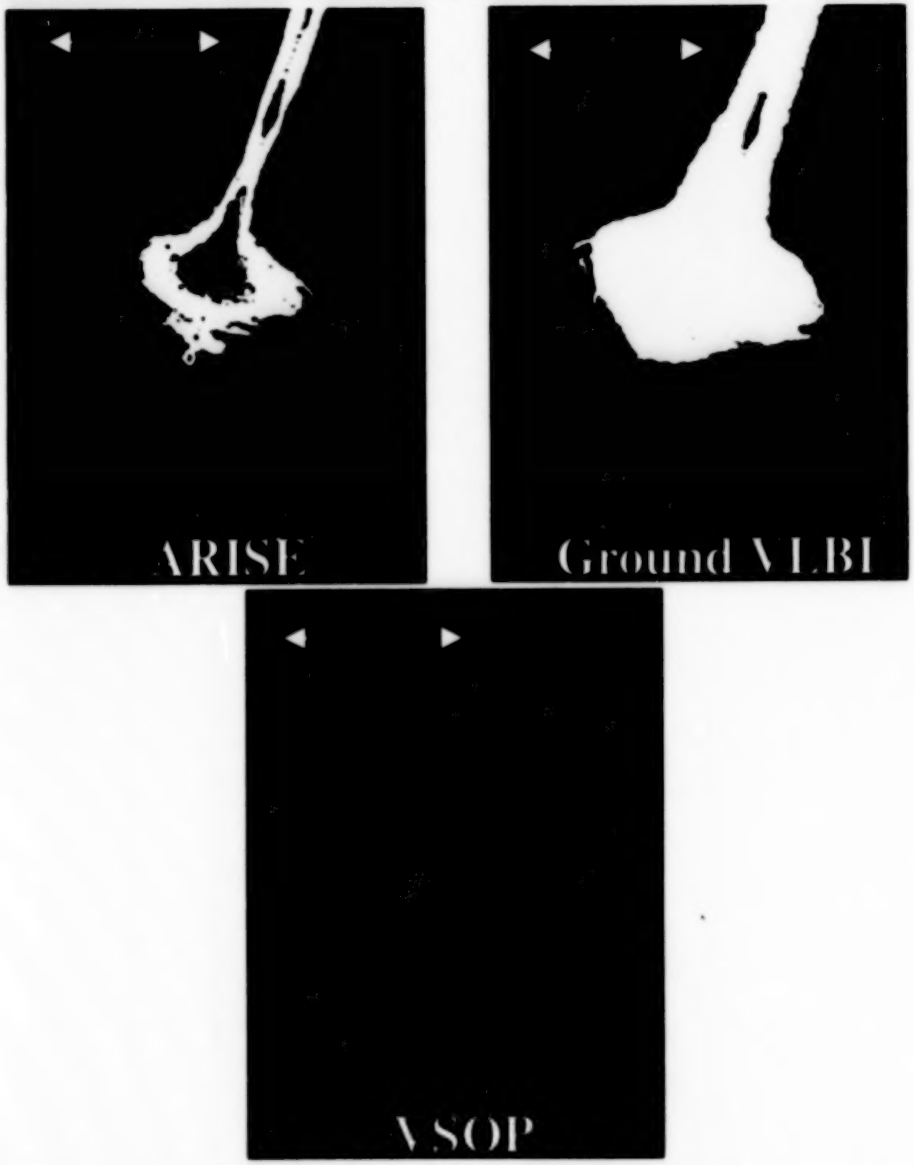
Supermassive Black Holes and Radio Jets
- AGN Fueling
- Relativistic Jet Production
- Generation of High Energy Photons

Accretion Disks and Megamasers
- Masses of Black Holes
- Nature of Megamaser Disks
- Accretion Processes
- Distance Measurements

Stellar Coronae
Gamma Ray Bursts
Supernovae

ARISE Imaging Capability

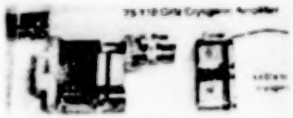




ARISE uses low energy photons to image high energy phenomena

ARISE New Technology Needs

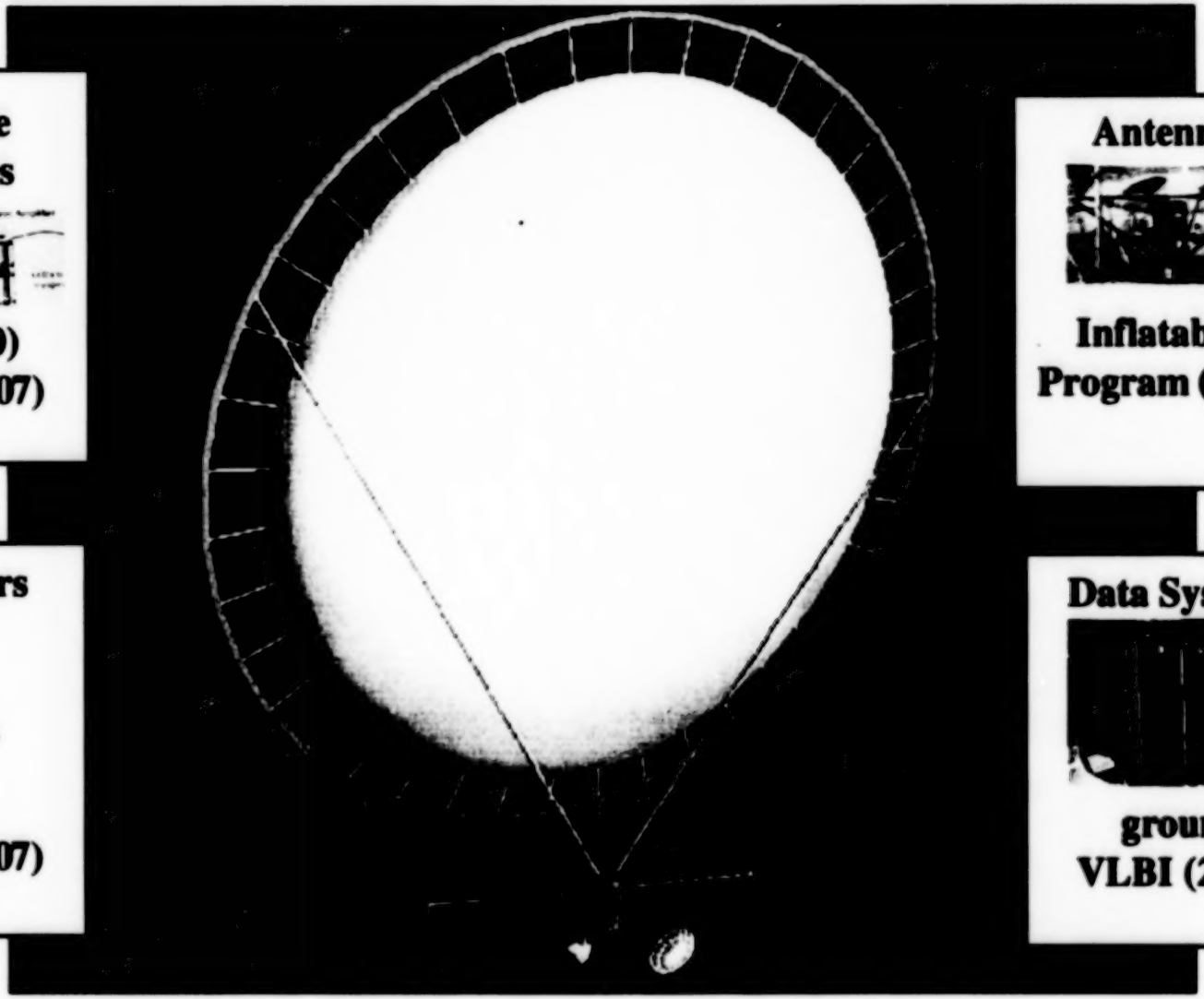
Low Noise Amplifiers



MAP (2000)
Planck (2007)

Cryocoolers

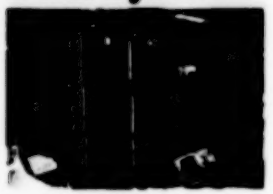
Planck (2007)



Antenna

Inflatables Program (2005)

Data Systems

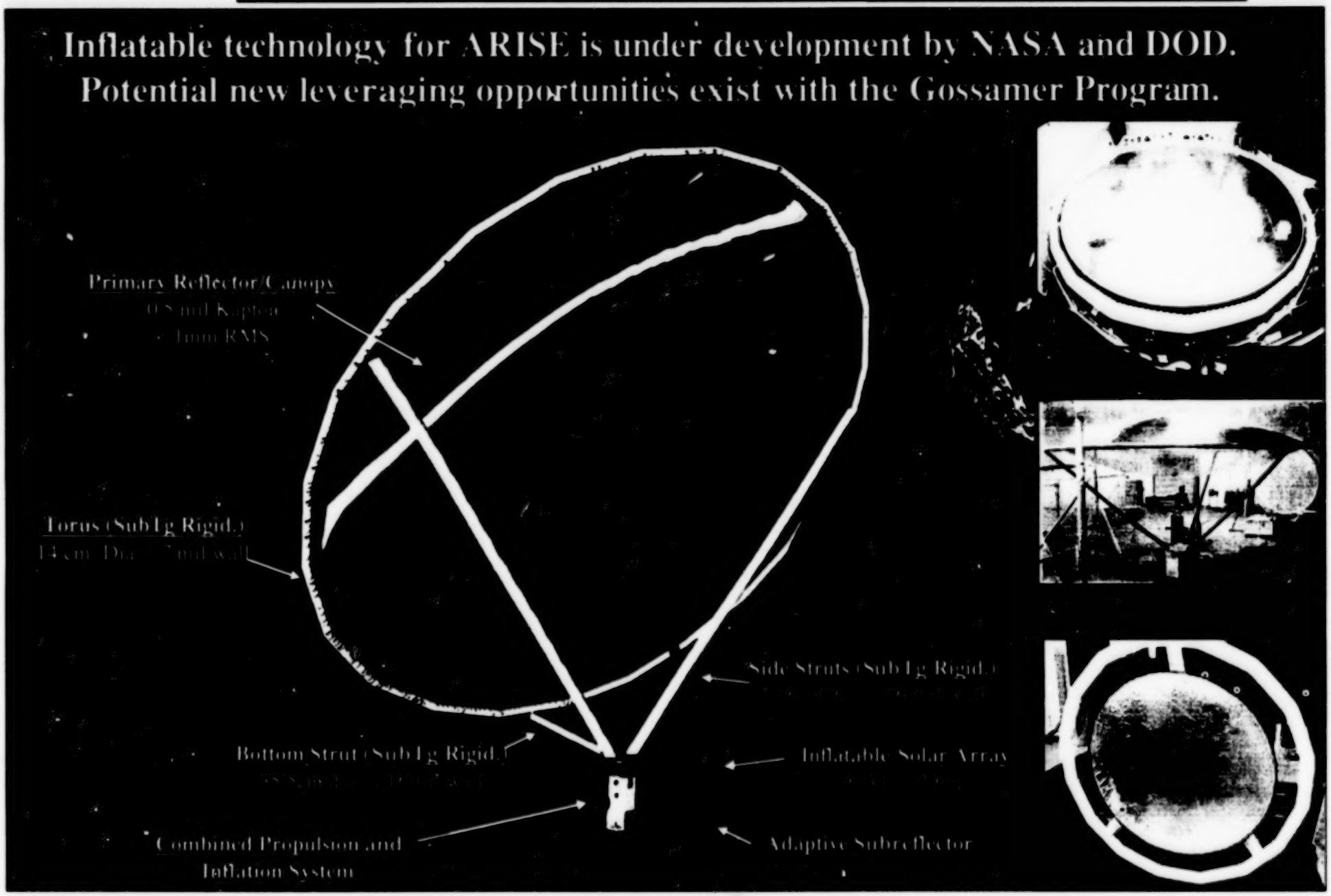


ground VLBI (2006)

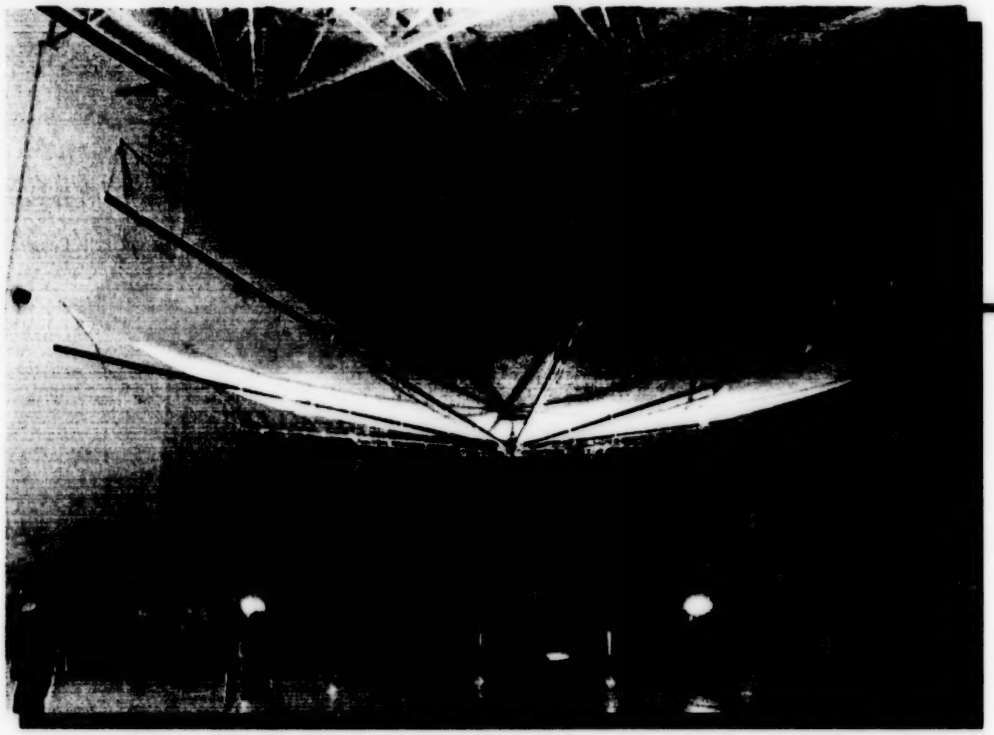
To increase science return at affordable cost ARISE will use new technology developed by other programs and missions.

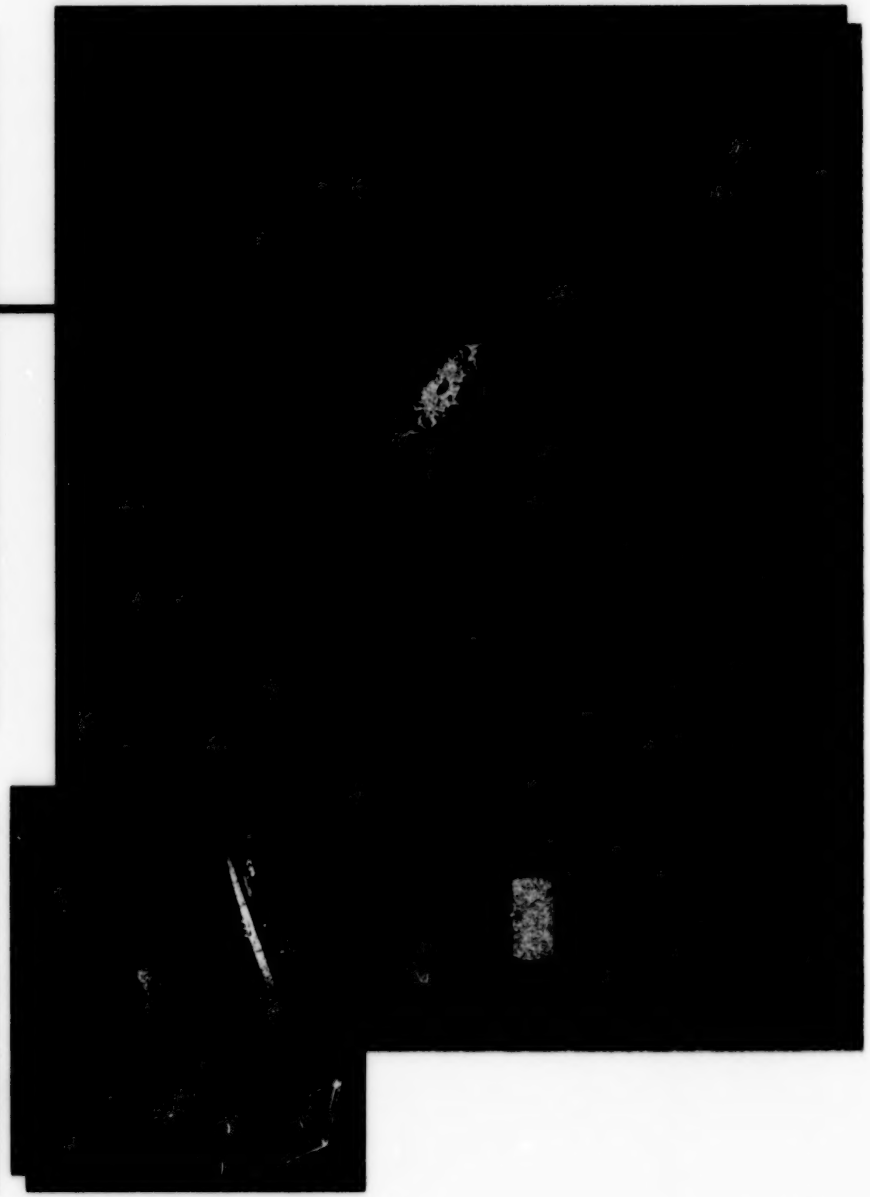
ARISE Inflatable Antenna

Inflatable technology for ARISE is under development by NASA and DOD.
Potential new leveraging opportunities exist with the Gossamer Program.



Mechanical Alternative to the Inflatable Antenna





Harris Corporation mesh antenna for ARISE.

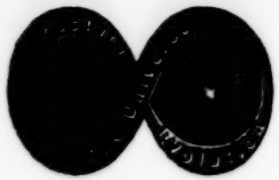
The 25 m diameter mesh antenna would operate up to 43 GHz. The inner 8 meter diameter shaped spline composite would assure performance at 86 GHz. The drawback of the mechanical concept is greater mass, stow volume and cost. The benefit is the extensive flight heritage (several large mesh antennas flown by DOD).

ARISE FY99 Accomplishments

Technical:
- Combined propulsion and inflation system design
- Adaptive feed conceptual design
- Adaptive feed Vs adaptive subreflector trade study
- Antenna deformation analysis
- Launch vehicle selection
- Antenna material evaluation
- Antenna RF performance characterization
- DSN implementation
- Cost comparison studies
- Recorder and correlator study
- Mission optimal orbit analysis
- Downlink modulation scheme study
- Mission operations analysis
- Alternative antenna rigidization analysis
- Mechanical antenna conceptual design

Publications:
- Spacecraft Document - Edition 1
- Spacecraft Document - Edition 2
- Science Executive Summary
- Science Goals Document
- Several scientific papers
- Media coverage

Activities:
- Several ARISE lectures
- Booth at AAS
- NRAO/JPL management meeting
- Discussions with Japanese
- Science Workshop
- Science Advisory Group telecons



ARISE Funding

- **Current sources of FY99 funding:**
  - $200K RTOP ⇒ Mission Studies @ JPL
  - $750K Cross-enterprise ⇒ Inflatable antenna components
  - Substantial DOD program with related goals
- **Technology Development/Mission Formulation Requirements**
  - $2-3M for ARISE antenna specific technology development
  - All aspects of the inflatable antenna will be developed under the Gossamer Technology funding
  - Phase A/B cost $55M
- **Implementation and Flight Operations**
  - Phase C/D cost $225M (20% contingency) + $60M for launch vehicle
  - Phase E cost $26M
  - ARISE looking forward to inclusion in FY00 OSS Strategic Plan

Dollar amounts in fixed year FY99 dollars

ARISE Outlook

ARISE is likely to be recommended by the Radio Panel of the Decade Committee

Broad US and international Science Advisory Group

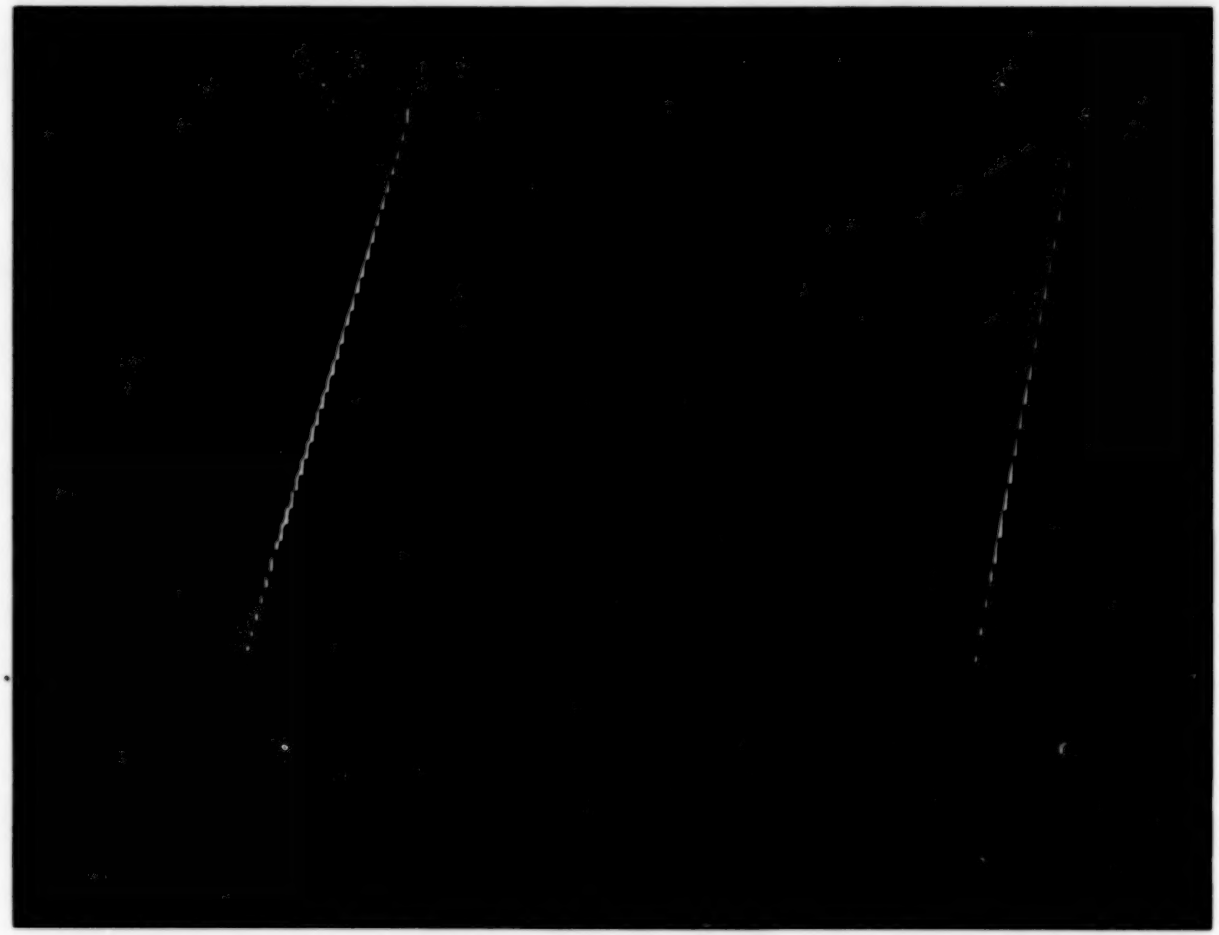
ARISE continues successful NASA/NSF cooperation

International collaboration

- **Strong participation in Science Advisory Group**
- **European VLBI community and ESA**
- **Recording systems and correlators - Canada & Europe**
- **Discussions with Japanese under way for ARISE/VSOP-2 collaboration**

Excellent support from CETDP on the inflatable antenna development

Orbiting Wide-angle Light collectors (OWL)



John P. Galloway
Goddard Space Flight Center
http://lheawww.gsfc.nasa.gov/docs/gamcosray/hecr/owl_new.html

The Limits of Energy: OWL Missions Goals

An Earth Orbiting Experiment to Study > 10^{20} eV Particles
by Observing Giant Air Showers from Space

Mystery: The origin of the highest energy cosmic rays observed in nature is not understood.

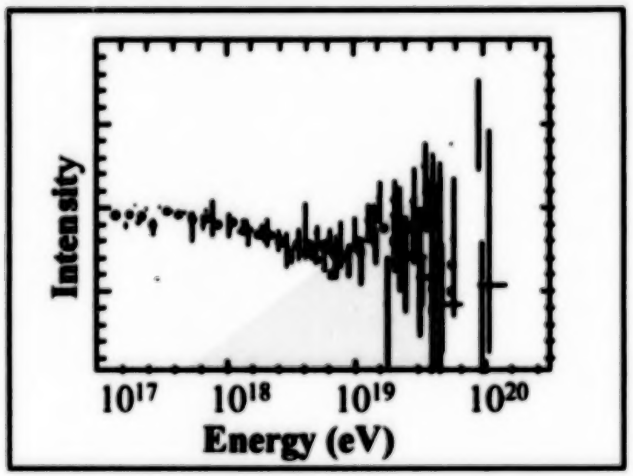
- Almost certainly extragalactic
- "Should" be cosmologically "local," but no candidate sources

===> Determine the characteristics and sources of these highest energy particles known in nature

- "Bottom-up": Acceleration by
  - Unipolar induction (e.g. spinning black hole)
  - Strong shocks
  - γ-ray blast
- "Top-down"
  - Decay products of "topological defects," relics from the creation of the Universe

===> "Open" the field of UHE ν astronomy

- A few neutrino events/year at e> 10^{19} eV



Mission Concept

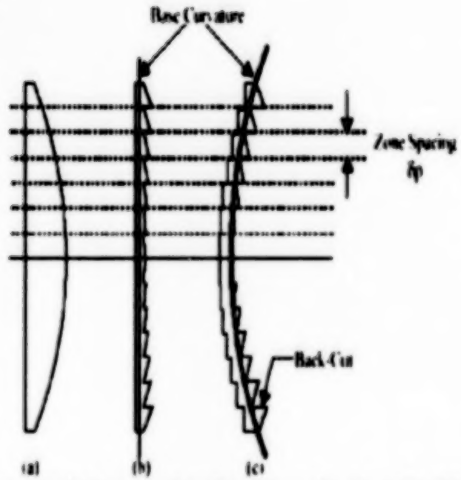
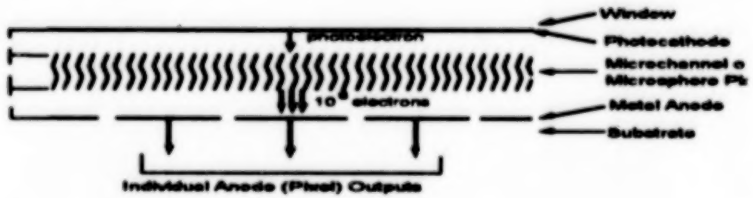


Figure 1. Standard lens (a) and two Fresnel lenses (b) and (c) derived from it.



- **Observe fluorescence light from air showers induced by incident high energy cosmic rays interacting with the atmosphere**
- **2 satellites, loose formation flying**
  - Stereo view of airshower development
  - 500 km equatorial orbits
  - 3 year mission lifetime
  - Delta III launch vehicle
- **Telescopes**
  - 4 meter diameter, wide Field Of View (FOV) optics
  - Thin, lightweight Fresnel lenses
- **Focal Plane Detectors**
  - ~30 square meter photocathode area
  - ~10^6 pixels with single photo-electron sensitivity
- **Electronics**
  - Microsecond sampling of ~10^6 channels requires low power
  - Single photoelectron sensitivity requires low noise
  - On-board event recognition, partial event reconstruction and background rejection required

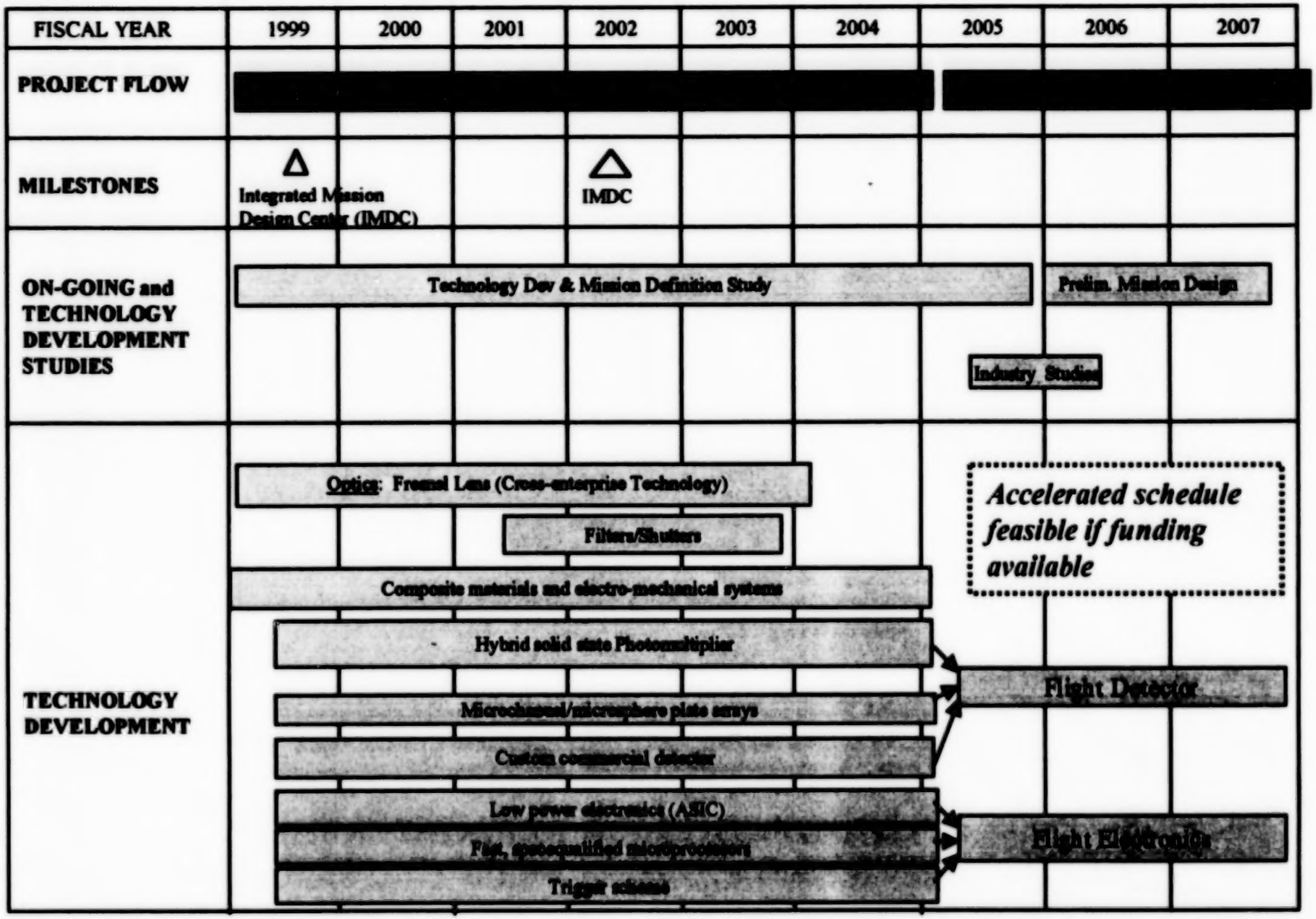
Potential Collaboration Opportunity

- **Informal discussions on collaboration with Italian scientists**
  - Italian mission is identical in science objectives and is called AIRWATCH
    - > single spacecraft (s/c) concept
    - > funding is ~$130K FY99, ~$1M FY00
    - > Italians will have a chance to propose to an ASI AO in '01 or later (cost capped, ~$140M)
    - > Dr. Bignami (ASI Director) is aware of OWL-AIRWATCH collaboration and intends to include this as a topic in the upcoming ASI-NASA meeting
  - Collaboration with the Italians is advantageous to the OWL mission
    - > cost sharing opportunity, resulting in smaller U.S. cost for total mission
    - > Italians have world-class expertise in this area of science
  - Areas to be worked
    - > process for approving a significant international collaboration
    - > determine if science goals can be met by one spacecraft
    - > "division of labor" between U.S. and Italians
    - > sources of U.S. funding

Technology Drivers

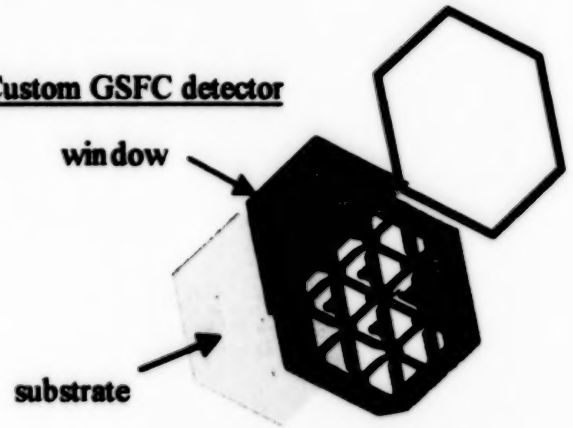
Technology Area	Technical Challenges	Key Technologies	Participants
Photon detectors for image focal plane	How to achieve single photon sensitivity over a large area, with low noise, good quantum efficiency and high "pixelization"; how to make a contoured, non-flat focal plane	Multi-anode microchannel/ microsphere plate arrays; Hybrid solid state photomultiplier; "custom" commercial detector	GSFC Industry Japan (?)
Electronics for fast image read-out	How to achieve low power readout of ~one million channels, deep buffering	Rad-hard, low power Application Specific Integrated Circuit (ASIC)	Italy/GSFC
Large Aperture Optics	How to achieve effective optical entrance aperture of ~4m diameter; angular aperture of ±30Υ(but low image resolution, ~0.1Υ)	Rad-hard, ultraviolet (UV) transmissive plastic lenses; Large UV bandpass filters	MSFC/UAH
Complex trigger system	How to achieve on-board pattern recognition of evolving air-shower; rejection of backgrounds; degree to which trigger should be hardware or software	Rad-hard, low power ASIC; Fast, space-qualified microprocessors	Italy
Placing large structure in orbit	How to package and mechanically deploy a large detector array in orbit	Composite materials; Electro-mechanical systems	GSFC

Technology Roadmap



Progress

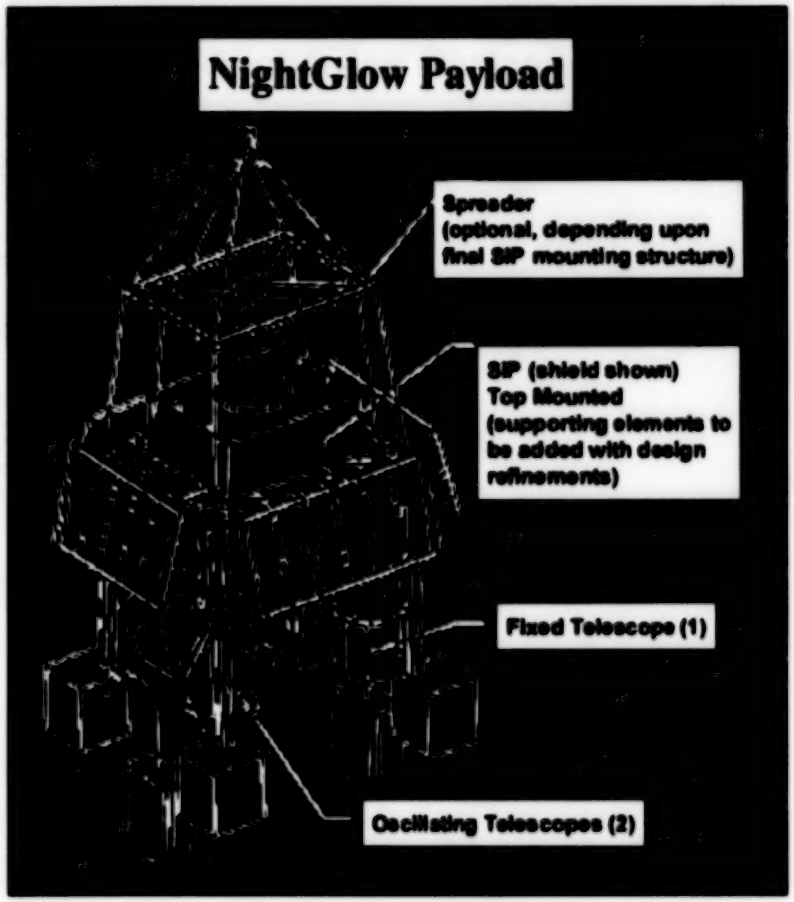
- **Presentation to National Academy of Sciences (NAS) National Research Council (NRC) Panel on Particle and Gravitational Wave Astrophysics (Gaisser Panel), March 26, 1999 in Atlanta, Georgia**
- **Successful OWL collaboration meeting October 98**
  - Strawman electronics design presented by Italians
  - Spacecraft concept presented by GSFC
  - Focal plane detector concepts discussed
    - > GSFC in-house design, funded through Director's Discretionary Fund (DDF)
    - > Hamamatsu "off-the-shelf" multi-anode photomultiplier tube (PMT)
- **MSFC/UAH cross-enterprise technology fresnel lens work**
  - Prototype lens fabricated, concept demonstrated
  - Candidate rad-tolerant, flight plastics for lens and filters have been identified and are being investigated
  - Web page for dissemination and exchange of information being developed

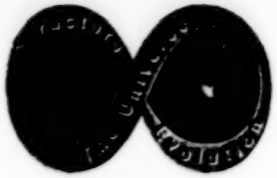


Prototype fresnel lens

Progress

- **GSFC in-house Monte Carlo model under development**
  - Detailed simulation of atmospheric cascade and instrument performance
  - Use as a tool to evaluate & quantify alternative design parameters
- **NIGHTGLOW experiment selected via NRA process**
  - 2001 balloon launch, will provide input on level & variability of the UV albedo as observed from space
  - This information is critical in determining the on-orbit threshhold levels for the OWL instrument





OWL Funding

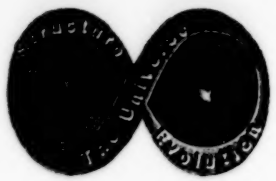
- **Current sources of FY99 funding:**
  - $50K RTOP ⇒ Mission Studies @ GSFC
  - $55K GSFC DDF ⇒ custom detector
  - $345K Cross-enterprise ⇒ fresnel lens
- **Technology Development/Mission Formulation Requirements**
  - $14M (does not include optics)
  - ~ $2M (thru 2003, renewable annually) of cross-enterprise technology development funding is available to MSFC to mature the fresnel lens technology to TRL 4/5
- **Implementation and Flight Operations**
  - ~ $350M mission total, 2 spacecraft concept, 3 year operational life
  - With Italian collaboration, implementing one spacecraft concept, U.S. contribution would be ~ $100M
  - OWL looking forward to inclusion in FY00 OSS Strategic Plan

Dollar amounts in fixed year FY99 dollars

The Outlook for OWL

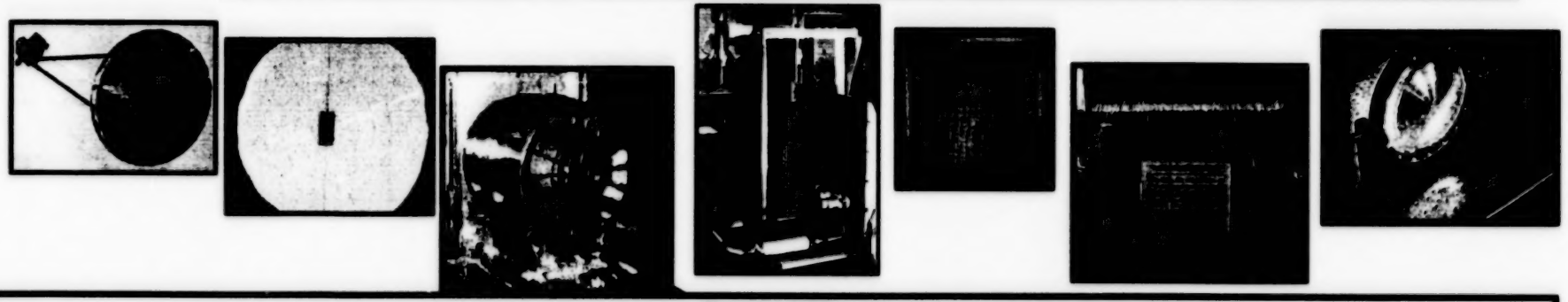
- **1-Year Outlook (Spring 2000)**
  - Flight optics materials selected and tested
  - Mission concept iterated and refined
  - NIGHTGLOW experiment design complete, hardware fabrication in-progress
  - Continued discussions with Italian collaborators on joint NASA/ASI mission
  - Discussions with potential partners
    - > DOE (presentation @ May 1999 Inner Space/Outer Space II conference)
    - > National Science Foundation (NSF)
    - > RIKEN Laboratory/JAPAN (Bob Streitmatter going to Japan in June 1999)

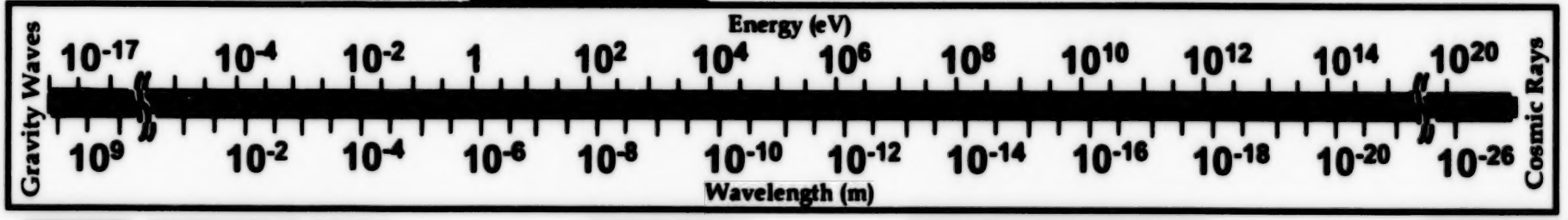
- **5-Year Outlook (Spring 2004)**
  - At the current level of funding through NASA, no substantitive technology development can occur; therefore, a 5-year outlook is not predictable
    - > Technology development (with the exception of the cross-enterprise funded fresnel lens work) will be "on hold" until funding is available



Concluding Remarks

SEU Advanced Technology Extends Across the Spectrum





Accele-rometers | HEMTs | Mixers | X-Ray Calorimeters | Silicon Detectors | Wide FOV Optics

μN Thrusters | Bolometers | Grazing Incidence Optics | Scintillating Fibers

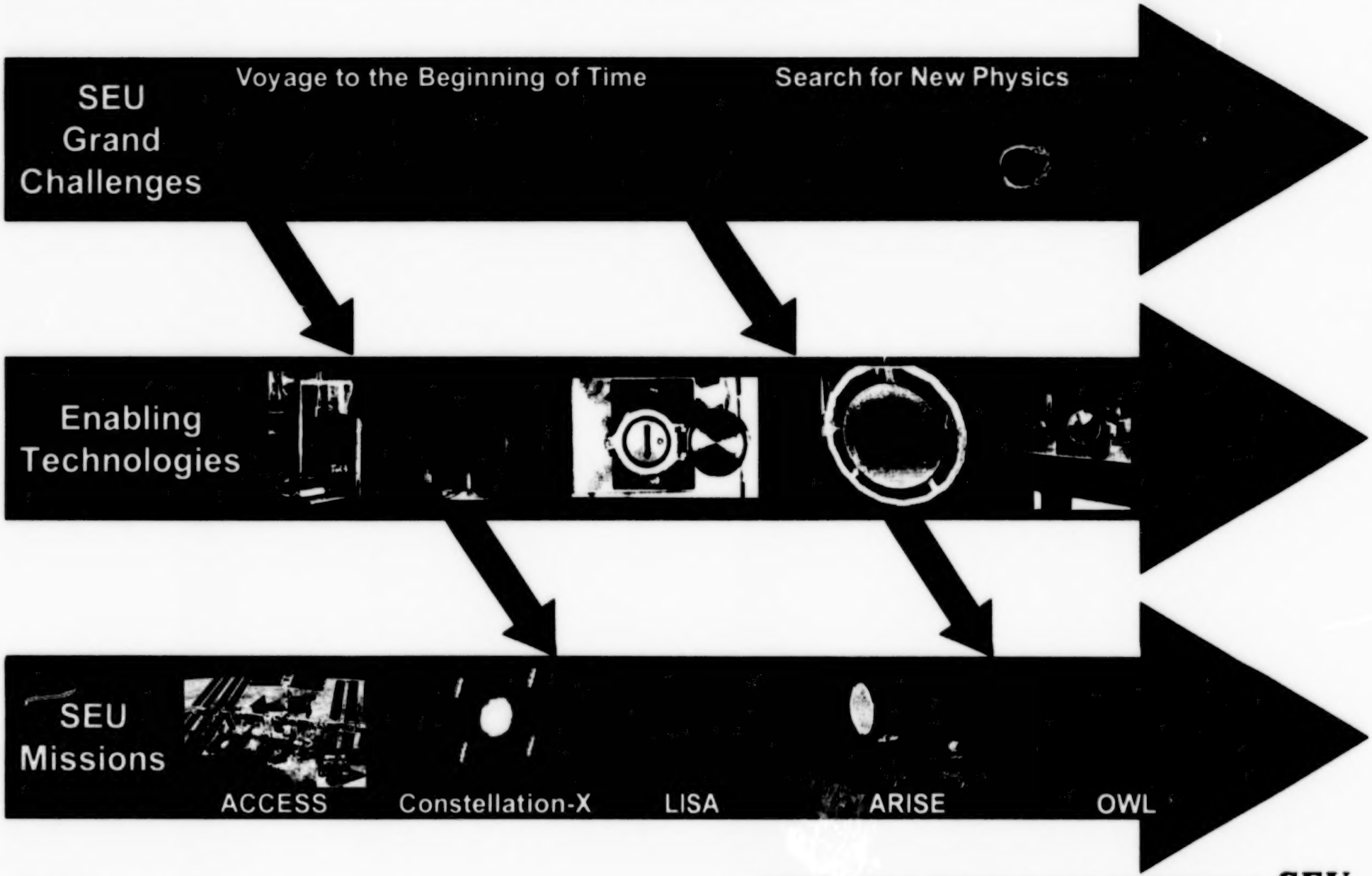
Inflatable Optics | Light, Large Optics | CdZnTe, Ge Arrays | Inflatable Optics

Cryocoolers | VLSI Electronics/ Analog ASICs

Extendible Structures

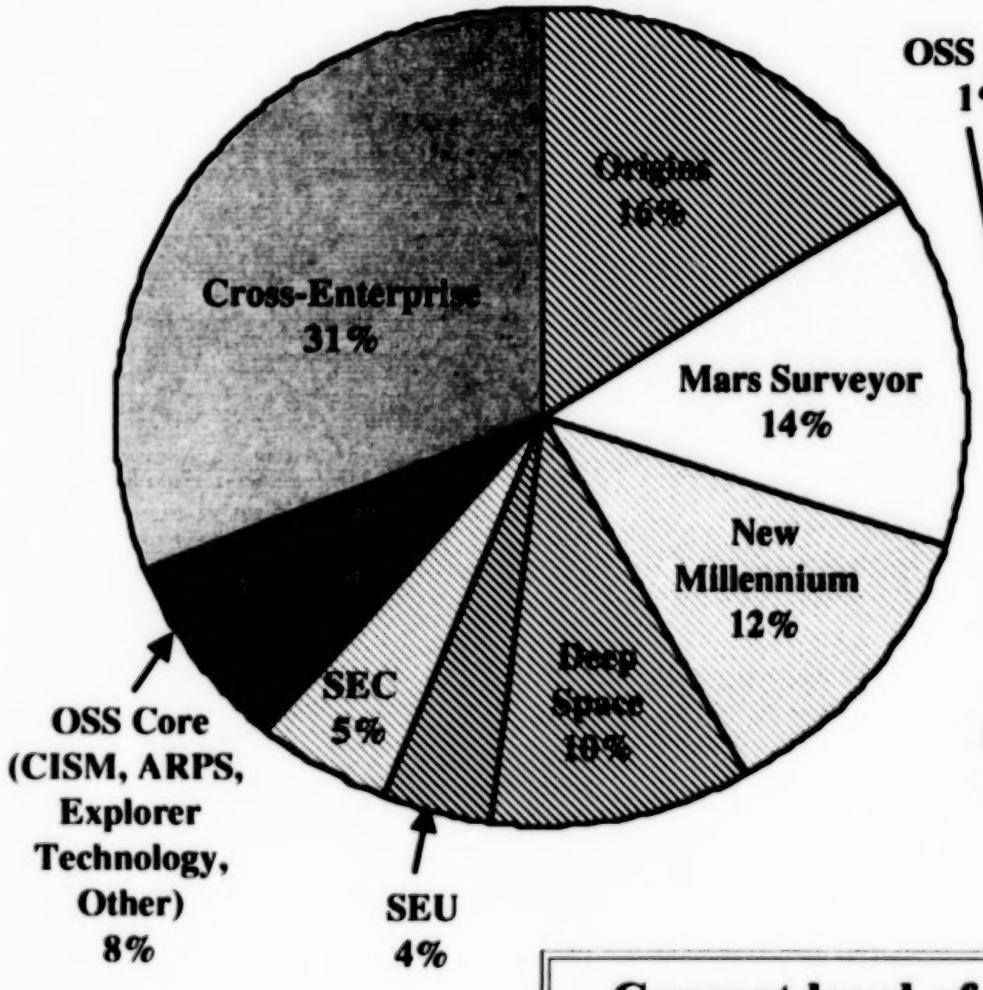
Leveraging resources: focused ATD, Cross-Enterprise, SR&T, SBIR

Technology - the Critical Component to Achieving SEU Science

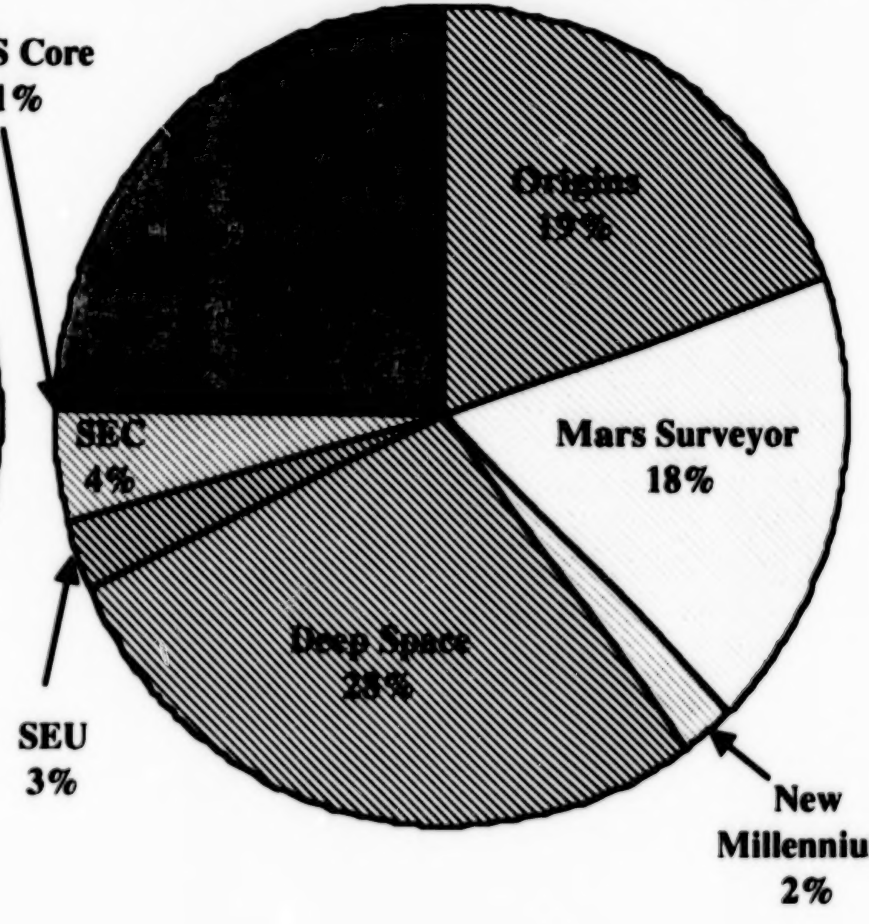


Advanced Technology and Mission Studies
Code SM Budget

FY99 (POP 99-1 Guidelines) = ~$500M



FY00 President's Budget = ~$680M



Current level of SEU focused ATD budget is inadequate to prepare for the Grand Challenges.

END

05-07-03